X-724-66-568

NASA TM X- 55764

DEVELOPMENT OF THE FABRICATION AND PACKAGING TECHNIQUES FOR THE ECHO II SATELLITE

DECEMBER 1966

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

DEVELOPMENT OF THE FABRICATION AND PACKAGING TECHNIQUES FOR THE ECHO II SATELLITE

James P. Talentino
Echo II Project

ABSTRACT

This document describes the techniques developed and used in processing the Echo II satellite from raw material to flight-ready hardware. The design concepts, fabrication and packaging techniques, improvements in techniques, and test methods are discussed.

X-724-66-568

DEVELOPMENT OF THE FABRICATION AND PACKAGING TECHNIQUES FOR THE ECHO II SATELLITE

James P. Talentino
Echo II Project

December 1966

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

TABLE OF CONTENTS

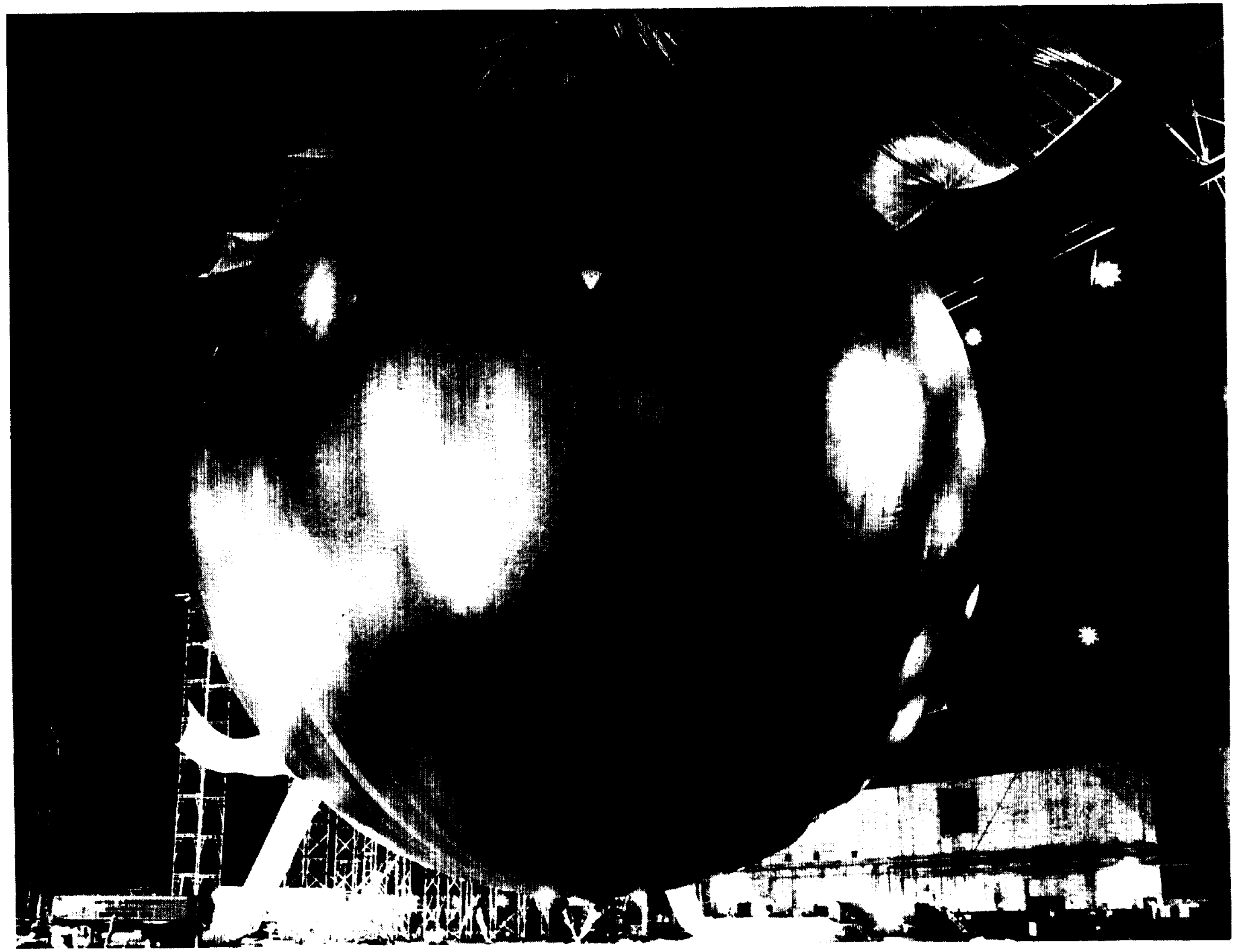
TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

ILLUSTRATIONS

TABLES



Frontispiece—Echo II in Static Inflation Test, Lakehurst, New Jersey

SECTION 1

INTRODUCTION

Echo II, launched and placed into orbit on January 25, 1964, from the Western Test Range, was developed from a program designed to investigate the feasibility of constructing and deploying a 135-foot diameter spherical strain-rigidizing passive communications satellite. This program was initiated early in 1961 to provide follow-on effort to the successful air-density and communications experiments conducted with Echo I, which was placed into orbit on August 12, 1960, from the Eastern Test Range.

The successful construction of 135-foot diameter spheres, which would be deployed in space and then shaped and rigidized by internal pressure from a subliming compound, was regarded as having a high probability based on the deployment of Echo I and extensive tests on Echo II material. The studies and investigations performed during the various phases of the program included structural design, material strength and weight relationships, material lamination parameters, thermal control coatings, rigidization pressure requirements, beacon area reinforcements, electrical conductivity of the surface, fabrication techniques, packing factors and methods, inflation materials and control methods, prelaunch evacuation techniques, effects of the space environment, and electromagnetic reflection properties.

Eighteen full-scale spheres were constructed during the Echo II program. These were used for design approval, for environmental, qualification and acceptance testing, and for the flight units. Appendix A presents the major function of each of the 18 spheres. Appendix B is a chronology of events pertaining to the program. Appendix C is the GSFC specification to which the flight units were fabricated and packaged. Appendix D lists the contractor's specification for fabrication and packaging the Echo II satellite. Appendix E lists the contractors that participated in the development and fabrication of the Echo II satellite.

This report describes the research, development, and testing techniques used to design, fabricate, and package Echo II. References 1 through 7 apply throughout.

SECTION 2

DESIGN STUDY

2.1 APPROACH

A study was conducted to determine the optimum design for the 135-foot diameter spherical shell considering the basic problems of weight, strength, mass concentration on the surface, stress distribution over the surface (considering requirements for seal tapes), cutting and assembling flat material to form a sphere, fabrication techniques, and reliability. The design tests were culminated by a test at the Naval Air Station, Weeksville, North Carolina, in which a 135-foot diameter prototype of Echo II was tested to destruction.

The design, fabrication, and packaging of the Echo II spheres were qualified through structural, environmental, packaging, and deployment tests designed to define the parameters necessary for launching the flight unit. These tests included static inflation, launch environment simulation, vacuum initial deployment, and suborbital flight. The details and results of the qualification tests leading to the orbital flight are reported in other Echo II project documents.

2.2 BASIC CONFIGURATION

Four designs were considered in selecting a basic configuration for the satellite (Figure 2-1).

2.2.1 DESIGN A

Design A, shown in Figure 2-1, was developed on the basis of gore calculations which defined the width of gores at points along a great circle. Spherical accuracy was obtained by smoothing the curves between the calculated points to avoid local irregularities in the surface. This was the basic design used on Echo I, and on many other types of inflatable spheres including superpressure balloons. This design had the advantage of using only one gore configuration and of having all the tape seals terminate in an area where the stress concentration could be controlled. (It has been determined for structures of this type that the gore stresses are carried into the seal tapes and then through the tapes to the polar caps. In this way, the stresses carried to the polar cap areas by the seal tapes were contained, and effectively each gore seal extended completely around the circumference of the balloon.) Another advantage of this system was that since all gores run the full length of the balloon, folding the gores for proper deployment from the canister was easily accomplished. The only disadvantage of this

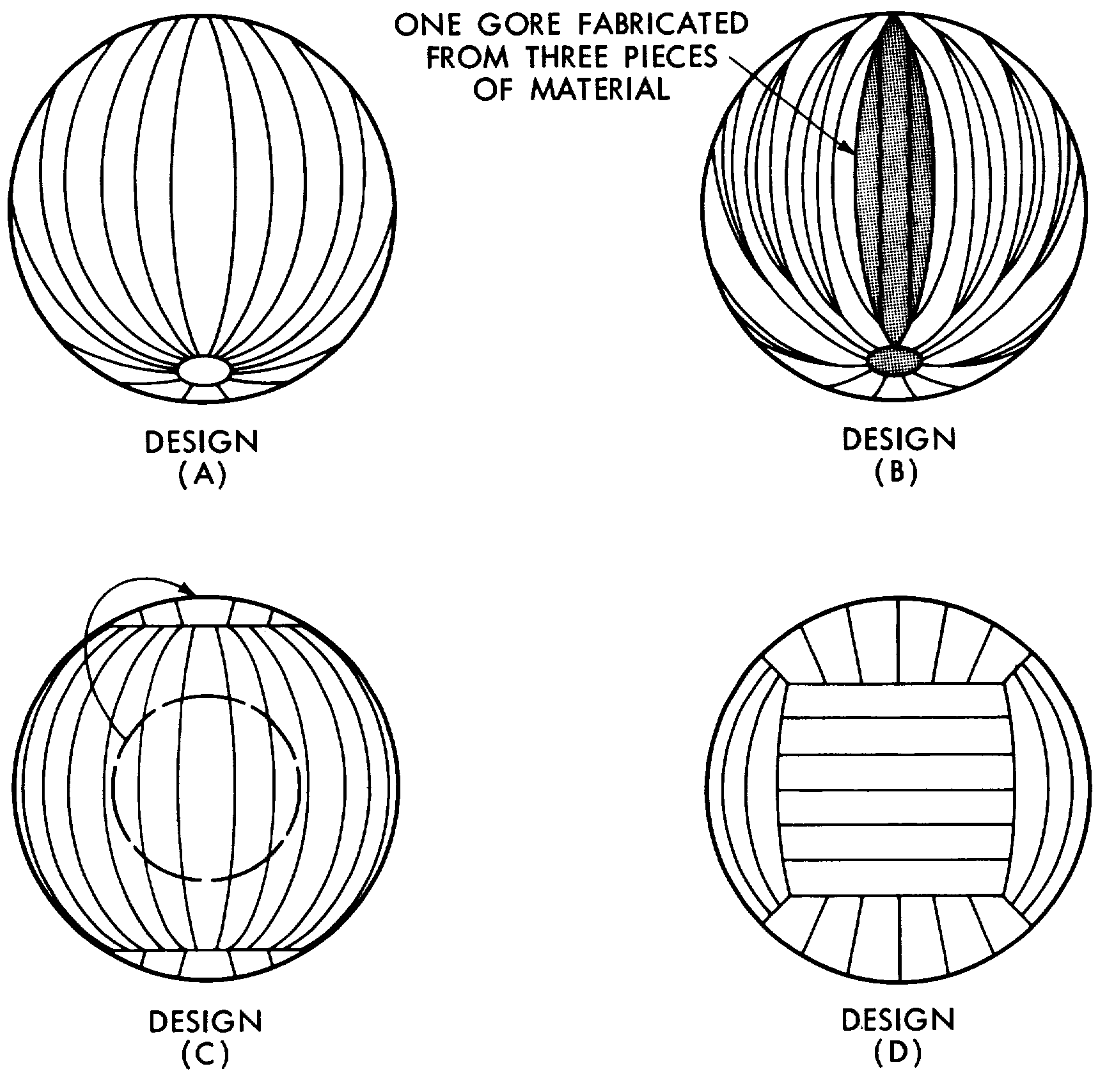


Figure 2-1. Basic Configurations

design over some of the others considered was that it had slightly greater mass concentration at the polar caps and slightly more seal length and weight.

2.2.2 DESIGN B

Design B was fabricated by first sealing three rectangular pieces of material together and then cutting out a single orange peel gore. This gore design reduced by two-thirds the number of orange-peel gore segments used in fabricating the sphere and saved in seal length. As Figure 2-1B shows, only one-third of the gores terminate at the polar cap, and two-thirds terminate at a point on the balloon surface. The main advantages of this design over design A were the reduction of seal length and a slight reduction in the mass concentration at the polar caps. The disadvantages, however, were that production equipment was not available which would handle gores totaling at least 12 feet in width, and that the gore tapes which did not terminate at the polar caps would carry their added stress to the termination point only, with no provision for distributing it further into the balloon skin. If these tapes were to be reinforced, the weight-saving generated from the shorter seal length would be virtually eliminated. Packaging of this design should have presented no more difficulties than design A.

2.2.3 DESIGN C

Figure 2-1C shows the basic sphere the same as in design A, but with the polar cap increased to approximately 30 feet in diameter. This polar cap was fabricated as a spherical segment using several gores sealed together. The main advantage of this design was the saving in overall seal length and weight. However, several problem areas were associated with this configuration.

a. The polar caps must be fabricated of gore material using a number of special pattern designs to obtain the desired shape. This complicates the fabrication and the maintenance of reliability.

b. All tape seals terminate abruptly someplace in a gore, and their stresses are not carried uniformly around the sphere. Evaluations made on other balloons have shown that high stress concentrations result where these tapes terminate.

c. The fabrication of the polar cap would require extensive development work to ensure proper alignment.

d. Handling of the balloon during fabrication would probably be the greatest problem, because the material would have to be moved several times during fabrication of the polar cap and again when sealing the polar cap to the balloon body itself. Moreover, this large cap would complicate folding the balloon for packing into the canister.

2.2.4 DESIGN D

Design D of Figure 2-1 had as its main advantage the saving of total seal length and weight. However, it had all the disadvantages of design C plus the necessity for more material handling during fabrication than did design C. Folding and packaging into the canister would have been more difficult than design C. Fabricating this design would have required five different patterns and extensive modifications to the sealing equipment.

Of the designs considered, design A appeared to be the best from the standpoint of strength, ultimate reliability, and ease of handling, sealing, folding, beacon installation, and inflation system installation. Although design A was slightly heavier than the other designs considered, its strength to weight ratio may have been higher than other designs. All of the sealing, except for the polar caps, could be done by machine and none of the material needed to be rehandled after sealing. This reduced the chances of damage to the material from excessive handling and from moving from one fabrication area to another as would have been necessary with the other designs.

2.3 STRUCTURAL TESTS—ROOM TEMPERATURE

To verify the findings of the basic configuration study, four different designs were selected for fabrication and test in the form of 12.5-foot diameter models. Two were of design A, one with and one without reinforced polar caps. The other two were of designs B and C. The basic construction material for all models was a three-ply laminate of aluminum and Mylar designated GT-15 (section 3.1 Material provides a detailed description). These spheres were tested to destruction to determine if the preliminary design analyses of the strength and stress concentrations were correct.

The spheres were instrumented with strain gauges distributed on the skin, tapes, and polar caps to determine the effects of stress at various points on the sphere. A U tube manometer was attached to the sphere to permit the measurement of internal pressure and the calculation of skin stresses. The spheres were inflated with air and photographs taken at various pressure levels and when unusual configurations were observed. All tests were conducted at room temperature.

Test sphere 1 (design A) was GT-15 material including the pole caps. At 1.5 inch H_2O (5800 psi skin stress) the pole caps were smooth and wrinkle-free, indicating a high stress condition. At 2.5 inch H_2O (9600 psi) one pole cap developed cracks in the aluminum. As pressurization continued the Mylar yielded, and at 5.5 inch of H_2O (21,200 psi skin stress) failure occurred in the pole cap. This test verified the prediction that reinforcement would be needed in the polar region because of the stress concentration.

Test sphere 2 was the same as sphere 1 except that the pole caps were reinforced with an additional layer of Mylar (GT-16 material). These reinforced pole caps showed no signs of high stress. At 5.5 inch H_2O (21,200 psi skin stress), the material began to tear near the equator. The tear propogated to and then around the pole cap. The pole caps were not damaged on either end indicating the effectiveness of the reinforcement.

Test sphere 3 was of design B with pole caps reinforced. Stress concentration occurred in the region between the pole cap and the point at which two tapes terminate on another. Although failure did not occur at this point, stresses in excess of 1.5 times the yield point were measured. The sphere failed near the equator in a gore at 23,900 psi skin stress.

Test sphere 4 (design C) indicated the problems associated with large-diameter pole caps. At 0.5 inch of H_2O the area near the pole cap was stressed considerably more than any other area. Failure occurred near the attachment of the pole cap to one of the gores, indicating the need for reinforcements at the ends of the tapes. Pressure at failure was 3.75 inch of H_2O (14,500 psi skin stress).

2.4 ENVIRONMENTAL TESTS

The objective of the tests conducted at Wright Air Development Center, April 3-6, 1961, was to determine the structural integrity of the Echo II sphere using 12.5-foot diameter scale models of design A, and to determine the stress-strain configuration of the sphere surface.

The test models were subjected to temperatures of -63°C to +100°C. Magnehelic pressure gauges measured the pressure differential of the inflated spheres at one atmosphere. These gauges were located outside the environmental test chamber and were not affected by the test temperatures.

Table 2-1 shows the ultimate stress levels reached on the 12.5-foot diameter spheres over a range of temperatures. Also shown is the average ultimate stress level of the tensile test samples at corresponding temperatures. Note the degree of correlation between the tensile test data and the sphere burst-point data. The stress computation is based on the Mylar thickness only.

2.5 PACKING TEST

Sphere 1, 135 feet in diameter, was fabricated and designated for canister packing tests to establish the packing factor and to permit freezing the canister design.

Two plastic canister sets were used in the tests. One had a packing factor of 2.5 and the other 3.0. Attempts to pack the sphere in the 2.5 canister failed as a result of false pleats and folds adding to the stack height. Several attempts were required with the 3.0 factor plastic canister employing slight rotation between each fold to use as much canister volume as possible. The canister design was frozen at a diameter of 39.6 inches and total height of 28.8 inches giving a packing factor of 3.0. The rotating fold method of packing used for this test is described in section 5.1.2.

Table 2-1

Composite Data for GT-15 Material
and 12.5-Foot Diameter Spheres Tested

Sphere No.	Temp (deg C)	Sphere Skin Stress Level Failure (psi)	Tensile (Instron) Test Avg. Ultimate Stress (psi) for GT-15 Material	
			Transverse	Longitudinal
Tests Conducted at WADD April 3, '61				
1	50	21,200	21,700	23,100
2	50	19,300	21,200	23,100
3	70	17,000	20,200	21,200
4	70	20,600	20,200	21,700
5	100	13,500	13,400	15,600
6	100	12,000	13,400	15,600
7	-59	25,800	39,700 (-56°C)	48,500
8	-44	26,400	39,700 (-56°C)	48,500
Low Temp. Test WADD Mar. 1, '61				
DR-185-1	-56	27,400	39,700 (-56°C)	48,500
DR-185-2	-56	27,000	39,700 (-56°C)	48,500
Room Temp. Test Mar. 14, '61				
DR-185-4	20	21,200	23,000 (25°C)	26,200
DR-185-4	20	21,200	23,000 (25°C)	26,200
DR-185-6	20	22,000	23,000 (25°C)	26,200
DR-185-7	20	25,800	23,000 (25°C)	26,200

2.6 STATIC INFLATION TEST (SIT)—WEEKSVILLE, N.C.

To qualify the basic design and techniques used to fabricate 135-foot diameter spheres, a full-scale static inflation test of sphere 2 was conducted in a dirigible hangar at the Naval Air Station, Weeksville, N.C., during May 15-19, 1961. The objectives of the test were to determine the structural integrity of the design, seal creepage, electrical continuity of the sphere, sphericity of the structure, rigidity and fold removal properties, and leakage rate.

The sphere, which weighed 530 lb, was inflated with a mixture of air and helium to provide enough lift so that it was not resting on the floor. Mixing of the gases prevented the helium and air from stratifying, which would have caused distortion of the sphere. This method of inflation was satisfactory in that no wrinkling or distortion was noticed.

The sphere was pressurized to 4,000 psi skin stress, the yield point of the material, and held at that level for 4 hours during the necessary tests. Following completion of all tests, the sphere was pressurized until it ruptured at 17,500 psi skin stress, which is about 85 percent of the ultimate material strength determined from tensile tests. A summary of the tests and results follows.

a. Seal Creepage—Seal creepage was determined to be nonexistent by the use of a spotting scope sighted on predetermined points of the sphere. After the balloon had ruptured, a close examination of these areas revealed no seal creepage.

b. Electrical Continuity—The object of this portion of the test was to determine the dc electrical conductivity of the aluminum foil laminate. A jumper strip was ultrasonically sealed across all the gores at both ends of the sphere to ensure positive electrical connection between all gores. To determine if all gores were electrically connected, a copper wire was attached to the top end cap of the sphere. A meter was connected to the bottom of the wire with a probe touching each gore at the bottom of the sphere; readings were taken before and during pressurization. It was concluded that adequate electrical continuity could be achieved with an ultrasonically sealed jumper strip.

c. Sphericity—The sphericity of the structure was determined to check sphere dimensions for compliance with the specification diameter requirements of 135 feet ±1 percent. Theodolite readings showed the diameter of the sphere at the equator to be 134.7 feet. The diameter through the poles was 135.9 feet. These two measurements represent the greatest deviation from the design diameter and both were within the allowable tolerances. With the use of circular transparent overlays and photographs, it was readily observed that the sphere was slightly football shaped, longer at the poles and shorter around the equator.

   During the initial pressurization, the surface was closely examined to detect bulges or flat spots. None was observed. It was noted that a number of alternately tight and loose rings were present perpendicular to seals. It was believed that these rings were caused by imperfections in the gore pattern. A new gore pattern with tighter tolerances was fabricated for use on all future spheres to correct this defect.

d. Rigidity and Fold Removal—During manufacture the bottom 30 feet of the sphere was folded and evacuated by methods similar to those to be employed during the folding and packing of the orbital sphere to check the fold removal properties of the material following pressurization to the yield point. For this test the skin stress was reduced from 4,000 psi to determine if the folds and wrinkles had been removed. The results were inconclusive since the pressure could not be completely released from the sphere due to requirements for supporting the sphere's weight. However, at the time of burst, the sphere momentarily lost pressure. Photographs taken before the sphere began to fall showed that the folds had been removed and rigidity of the skin achieved.

e. Leakage Rate—Since the internal pressure of the sphere was so low and its volume so large, temperature fluctuations masked any possible pressure change which might have been caused by leakage. It was, therefore, impossible to determine an absolute leakage rate. However, since the sphere required very little excess air to hold pressure during the night, the leakage was considered negligible.

Table 3-1

Typical Properties of
Alodine Coated Echo II Laminates

	GT-15	GT-15-1	GT-15-2 First Run	GT-15-2 Second Run	GT-15-3
Web coated with adhesive	Mylar	Mylar	Mylar	Mylar	Aluminum
Lamination temperature	340° F	300° F	270° F	270° F	300° F
Web tension	Medium	Low	Low	Low	Low
Web speed	12-20 fpm	15-20 fpm	15-20 fpm	15-20 fpm	14-16 fpm
Core size	3" I. D.	3" I. D.	3" I. D.	6" I. D.	6" I. D.
Percent shrinkage nominal					
MD -3 days	—	0.63	0.81	0.54	0.73
-6 days	—	0.83	0.90	0.62	0.85
Percent elongation nominal					
-MD	—	—	13.0	18.0	—
-TD	—	—	21.0	28.0	—
Yield strength lb/in nominal					
-MD	2.5	2.0	2.9	2.6	2.4
-TD	2.6	2.4	2.6	2.7	2.0
Ultimate strength lb/in					
-MD	9.7	10.0	11.9	11.9	11.8
-TD	10.1	12.0	11.9	13.9	11.4
Burst pressure, millibars for 10" diaphragm	—	165.2	174.6	189.4	159.0

NOTE: MD = machine direction; TD - transverse direction

SECTION 3

FABRICATION

3.1 MATERIAL

The basic laminate material (Figure 3-1) selected as a result of extensive research consisted of 0.18 mil ±10 percent aluminum foil 1080-0 bonded to both sides of 0.35 mil Mylar* plastic film with a 0.01 mil thick layer of GT**301 adhesive. The gauge of the foil was based on the minimum rollable thickness at that time. The laminate material was designated X-15 and GT-15 during the program experimental and production phases, respectively.

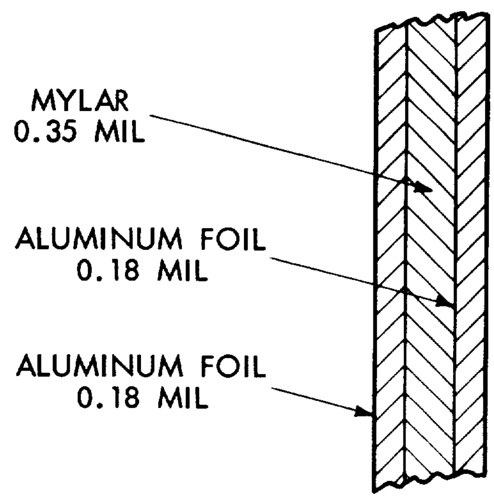


Figure 3-1. Cross Section of Echo II Material

Experimental work had shown that the laminate possessed properties of high-tear resistance, ability to withstand temperature extremes, and excellent resistance to the self-destructive action of one layer acting against another during deployment. Tests had been developed to demonstrate that the adhesive system used on Mylar and demonstrated through extensive tests and criteria received from the deployment of Echo I was also applicable to the aluminum laminate selected for this program. Tables 3-1 and 3-2 show the properties of the laminate developed under this program. The stress strain behavior of the material is shown in Figure 3-2. A detailed treatment of the mechanical and physical properties can be found in references 8 and 9.

The raw materials used in the program were purchased subject to certification by the vendors to specifications prepared to yield the quality products required. Tests were conducted on material from the outer portions of each incoming roll of aluminum and Mylar. Adhesive ingredients, solvents, viscosity, and total solids content were controlled. Raw material lot control and in-process inspection was maintained through all phases of material processing and fabrication.

---

*Registered trademark E. I. du Pont de Nemours and Co., Inc.
**Registered trademark G. T. Schjeldahl Co.

Table 3-2

Material Properties

Property	SIT Sphere 16	Backup Sphere 17	Orbital Sphere 18	GT-15-2 First Run Roll Nos. 413-440	GT-15-2 Second Run Roll Nos. 456-471
Ultimate tensile strength-lb/in					
Strain rate = 2 in/min					
Machine direction (lbs/in)	11.837 ±1.461	11.793 ±1.551	12.035 ±1.281	11.855 ±1.983	11.760 ±1.215
Transverse direction	12.825 ±0.998	12.277 ±2.874	13.915 ±2.067	11.899 ±2.667	13.879 ±1.755
Yield strength-lb/in					
Strain rate = 2 in/min					
Machine direction (lbs/in)	2.930 ±2.076	2.961 ±1.851	2.643 ±1.704		
Transverse direction	2.746 ±1.794	2.824 ±1.686	2.713 ±1.662		
Elongation (%)					
Machine direction	16.030 ±20.040	*	18.290 ±20.250		
Transverse direction	25.142 ±17.898	*	27.766 ±17.100		
Burst test (millibars)	180.960 ±49.890	177.500 ±43.470	190.460 ±42.375	174.588 ±55.629	189.375 ±43.170
Shrinkage (%)					
Three day-					
Machine direction	0.672 ±0.896	0.805 ±0.591	0.535 ±0.366		
Transverse direction	*	*	*		
Six day-					
Machine direction	0.787 ±0.696	0.897 ±0.570	0.616 ±0.354		
Transverse direction	*	*	*		
Coating weights (mg/ft^2)	**	184.201 ±8.070	183.401 ±8.415		

*Insufficient data for valid analysis.

**Gores were not selected according to Alodine coating weight.

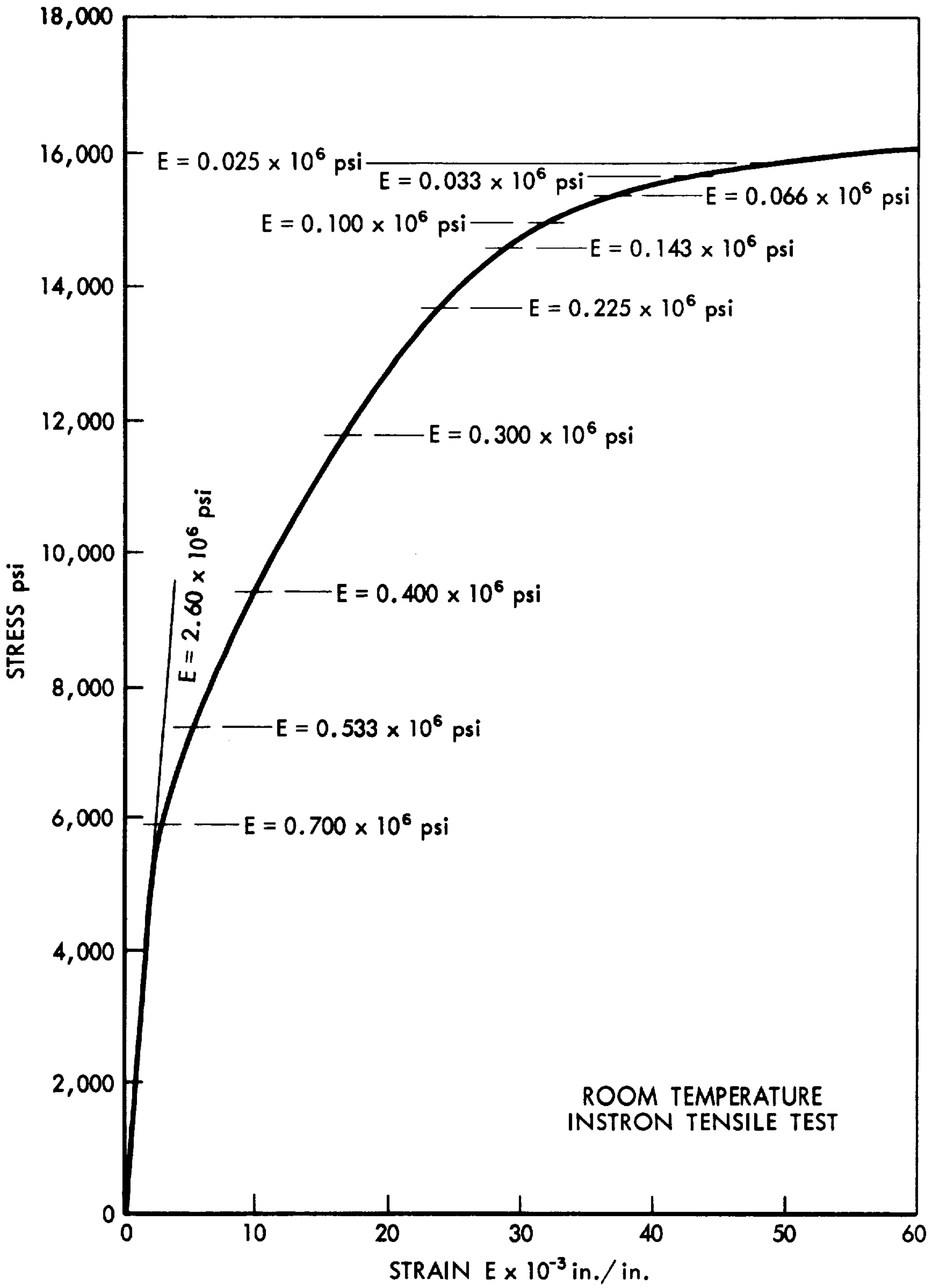


Figure 3-2. Stress-Strain Diagram for Echo II Material

3.1.1 QUALIFICATION OF MATERIAL FOR ORBITAL SPHERE 18

The material used in orbital sphere 18 and backup sphere 17 was to have been qualified by representation in Static Inflation Test sphere 16. Sphere 16 was to have contained at least one gore from each of the rolls of material used in the fabrication of spheres 17 and 18. However, owing to a combination of unfortunate events, sphere 18 and part of sphere 17 was not represented in sphere 16. Therefore, to qualify the material to be used in sphere 18, and part of sphere 17, a series of small-scale inflation tests was performed on 12.5-foot diameter spheres.

Six 24-gore 12.5-foot diameter spheres were fabricated from slightly imperfect 135-foot sphere gores taken from the material run for orbital sphere 18. The gores for one half of each balloon was made up of one 135-foot sphere parent gore. The spheres were fitted with endcaps and bonded with splice tape of material identical to the large balloon. Two small plastic inflation fittings were installed on each balloon to facilitate inflation and pressure sensing.

The spheres were tested at room temperature (about 70° F). The test plan consisted of inflation, checking for minor leaks, pressurization for 8 hours at 12,000 psi skin stress (based on a skin thickness, $t = 3.6 \times 10^{-4}$ inches). Following the constant pressure test, a rupture test was run on five of the spheres to determine the effects of the prolonged test and the ultimate pressure capabilities. In this test the pressure was increased slowly (about 2 hours) from 12,000 to 23,000 psi; at this time a final check was made on the spheres for foil fractures and general appearance. The pressure was then increased rapidly (about 5 minutes) until the spheres ruptured. The five spheres ruptured at skin stresses in excess of 25,000 psi. The sixth sphere was inflated, pressurized, and tested as the previous spheres except for the rupture test. This sphere was held at 25,200 psi for 5 minutes and then deflated. Table 3-3 indicates results of the tests.

All spheres exhibited good-quality construction and withstood skin stress greatly in excess of requirements. No seal or material creep was noted on the spheres after the 8-hour constant pressure test. All of the ruptures were catastrophic and the two spheres which failed around the equator demonstrated failure typical of ideal design and fabrication. These tests and the SIT of sphere 16 which withstood 23,000 psi conclusively demonstrated the structural integrity of the material used in orbital sphere 18.

3.1.2 ALUMINUM FOIL

Aluminum alloy 1145-0, 0.2 mil thick was used early in the program for spheres 1 and 2. As material and methods for processing them were developed, a lower

Table 3-3
Inflation Tests of 12.5-Foot Diameter Sphere

Sphere No.	Gores Used	Roll Represented	Burst Press (inches H_2O)	Skin Stress (psi)	Remarks
1	4925 4939	457-1 458-1	7.05	26,900	Rupture started near equator and tore along seals to end cap.
2	4956 5077	459-1 464-1-A	6.60	25,200	Rupture started in center of seal and propagated to both ends of seal.
3	4995 5022	465-1 466-1	7.10	27,300	Rupture occurred around equator.
4	5065 5135	468-1 469-1	7.10	27,300	8 hour constant pressure test run at 15,000 psi instead of 12,000 psi. Rupture tore across one gore and followed seal to end caps.
5	5119 5181	471-1 462-1	7.15	27,400	Rupture occurred around equator.
6	5106 5163	470-1 463-1	6.60	25,200	At 0 pressure after pressurization sequence, sphere was well rigidized. Top half sphere maintained shape throughout deflation.

yield point alloy, 1080-0, was introduced. This foil, produced by Alcoa to 99.9 percent minimum purity requirements and fully annealed, was 0.2 mil thick and 54 inches wide. The thickness was later reduced to 0.18 mil as the processing methods were improved. Towards the end of the program, fabrication of spheres 16, 17, and 18, the foil was supplied with thickness on the low side of the 0.18 mil ±10 percent tolerance or close to 0.16 mil.

The selection of 1080 over 1145 was based on a slightly lower yield point which would require less internal pressure to rigidize. The yield properties of the two alloys are compared below:

	1080	1145
Machine direction	2.0-3.0 lb per in.	3.0-4.0 lb per in.
Transverse direction	1.5-2.0 lb per in.	2.0-3.0 lb per in.

The modulus or yield point reported was that obtained for the alloy in large thickness, because determination of the modulus of the thin foil was very difficult. The behavior of the laminate materials, however, indicated a consistently lower yield strength in the transverse direction as compared to machine direction.

The annealing operation in the manufacture of the foil was carefully controlled so that the surface was sufficiently free of residual material to permit wetting with a 20 percent isopropanol solution. This ensured the absence of rolling oils which would have interfered with the development of the laminate bond and may have contaminated the Alodine coating operation.

Throughout the production operation, the quality of the foil was steadily improved despite the fact that the thickness was continually reduced. Although Alcoa made every effort to supply defect-free material, some small areas of cracked or stressed foil were received. Reinspection at the receiving point was not possible because of fragility of the material. Complete inspection during the lamination process revealed this defect.

3.1.3 MYLAR

The Mylar used was duPont 35 gauge (0.35 mil ±10 percent thick) designated type C. This grade of material, produced for use in electrical capacitors, has an extremely low electrical fault content and highly reproducible physical properties. Samples of all Mylar used in the program received during receiving inspection were subjected to tensile and elongation tests.

Castoff is a condition in which one edge of a material web is shorter than the other parallel edge, causing the web to lay in a bowed position. Gauge bands, a condition where the material thickness varies across the web producing random bands of constant thickness along the length of the web, are believed to contribute to castoff.

Although some castoff was observed early in the program, realignment of the lamination equipment made it possible to process the laminate without the gores having castoff so severe that cutting would be impossible. The minor amounts of castoff which did occur did not seriously interfere with any subsequent operations.

3.1.4 ADHESIVE

The adhesive used was GT 301, a proprietary item of the G. T. Schjeldahl Co. It was applied to the Mylar web by reverse roll coating a dilute solution in methyelene chloride and was dried in a "camel back" tunnel of the laminator before lamination with the aluminum. This operation was found to be moisture-sensitive, as the absorption of the heat of vaporization of the solvent resulted in cooling the equipment below the dew point at the coating roll, the coating idler, and part way into the drying tunnel. This situation, which became particularly severe during high-humidity conditions in warm weather, led to some modification of process and equipment to avoid the production of defective material.

The precautions taken generally consisted of:

a. Frequent changing of adhesive

b. Introducing desicated air near the coating roll and in the drying tunnel

c. Choosing operating time during which the humidity was most likely to be in the lower range

3.2 LAMINATION

3.2.1 BASIC PROCESS

The laminate material for all the Echo II spheres was prepared by passing the Mylar over the adhesive coating roll, through a drying tunnel, and into a nip between a heated steel roll and a rubber backup roll, where it was combined with the aluminum foil to form the first-pass laminate. After the roll of first-pass laminate was completed, it was then passed over the adhesive coating roll on the Mylar side, through the drying tunnel and into the nip where it was combined with the second layer of aluminum foil.

The equipment used (Figures 3-3 and 3-4) was capable of laminating webs up to 64 inches wide. Later in the program an 84-inch laminator (Figure 3-5) was used. The larger laminator, however, was believed to have caused the overlap defect in the Mylar during lamination, which is discussed later, and was abandoned for the 64-inch laminator during fabrication of spheres 16, 17, and 18.

The production laminate for spheres 1 through 15 was made to GT-15 material specification which provided for a 340°F hot roll temperature, 12-20 feet per minute web speed, and medium web tension. The laminate for spheres 16, 17, and 18 was produced as GT-15-2, which called for minimum web tension, a hot roll temperature of 270°F, and a web speed of 15-20 feet per minute. Tables 3-1 and 3-2 compare the properties of the production laminates.

The lamination procedures required careful adjustment to allow the handling of the very thin aluminum foil without excessive yielding or tearing. In the handling of the first-pass lamination, tension required to keep the web flat had to be applied very cautiously, as excess tension caused the aluminum to fracture.

All rolls of laminate were numbered consecutively, and identification was maintained throughout all processes to completion of sphere fabrication.

3.2.2 MATERIAL IMPROVEMENT STUDY

3.2.2.1 Weight Reduction

In an attempt to reduce the weight of the GT-15 laminate material, the individual components were studied for possible weight reduction.

a. Aluminum Foil—By improving their processes, Alcoa supplied foil approximately 0.00017 inch thick instead of the previously supplied 0.00018-inch thick foil. This decrease in thickness reduced the laminate weight by about 1 gram per square yard.

b. Mylar—Although Mylar was available in thinner gauges than 0.35 mil, it is very difficult to handle and is not sufficiently strong to be practical. Therefore, no weight reduction was realized from the Mylar member of the laminate.

c. Adhesive—Several attempts were made to reduce the thickness of the adhesives coating, but were found to have little or no effect on the resulting weight.

Figure 3-3. Sixty-Four-Inch Laminator (G. T. Schjeldahl Co.)

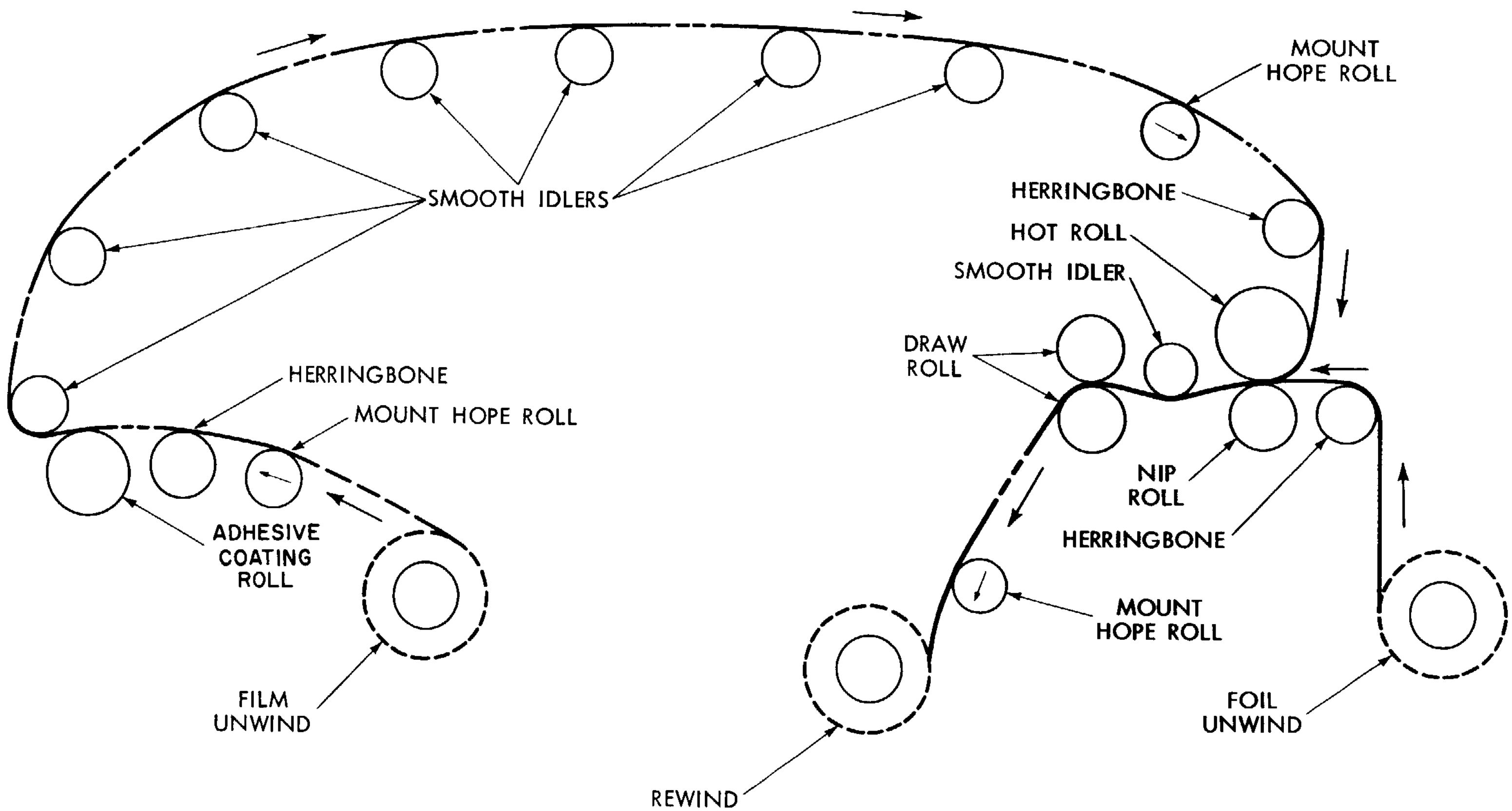


Figure 3-4. Schematic Diagram of Sixty-Four-Inch Laminator

Figure 3-5. Eighty-Four-Inch Laminator (G. T. Schjeldahl Co.)

3.2.2.2 Castoff Reduction

As previously stated, castoff is a condition in which one edge of a web is longer than the other; when a web is removed from a roll, instead of lying straight, it curves if it is to lie flat. Attempts to lay it flat results in wrinkles in the web.

The duPont Company suggested that castoff could be reduced by supplying the Mylar on 6-inch diameter cores and that 6-inch diameter rollers be used on all the rewinds in processing. The duPont Company felt that these 6-inch cores would help to reduce castoff by reducing the number of layers of film on a roll. They felt that some of the castoff was caused by thick gauge bands. When a thick gauge band occurs and the film is wound tightly many times, it is stressed and castoff occurs.

To minimize castoff, individual rolls of Mylar were carefully selected for uniformity and absence of gauge bands. The duPont Company cooperated by selecting and preparing rolls of Mylar from mill rolls with a minimum of castoff and gauge bands.

Castoff can also be caused during the lamination process. If rollers are not aligned perfectly, one side of the laminate can be stretched and when unrolled will have castoff. Modifications made to the laminator to improve this situation are discussed later.

3.2.2.3 Overlap Defect Investigation

Sphere 11 ruptured prematurely (Figure 3-6) during a static inflation test at Lakehurst, New Jersey, on June 13, 1963. Before rupture the sphere was successfully pressurized and relaxed according to the following schedule:

Date	Pressure Level (inches H_2O)	Skin Stress	Remarks
6-11-63		751	
6-11-63		1501	
6-12-63	0.064	2781	
6-12-63	0.114	4801	
6-13-63	0.154	6200	Gore 37 rupture

The origin of the fracture occurred in gore 37 and proceeded to propagate vertically in both directions generating separate fracture paths.

Figure 3-6. Sphere 11 Rupture

Visual examination of the fracture edges (Figure 3-7) and adjacent area indicated the presence of numerous surface flaws of a particular type and in varying degrees of severity. Samples were removed from the fractured material and were subjected to metallographic examination at GSFC (Figure 3-8).

The results of the examinations indicated that this particular condition was developed in at least the following two ways (A and B of Figure 3-9):

a. The Mylar film developed a fold prior to the first laminating stage.

b. The Mylar fold developed after the initial lamination but before the application of the second layer of foil. Figure 3-10 shows a material defect before and after rupture.

Tensile tests on samples removed from the defective area revealed a significant reduction in tensile strength properties due to this particular defect. Specimens having defects failed at loads ranging from approximately 3-7 lb with most averaging 6 lb, while samples of defect-free material could be loaded to 10 lb or more.

Balanced biaxial tests (diaphragm tests) were conducted at GSFC using 13-inch diameter specimens. Plain Mylar and aluminum foil were tested as well as the GT-15 laminate:

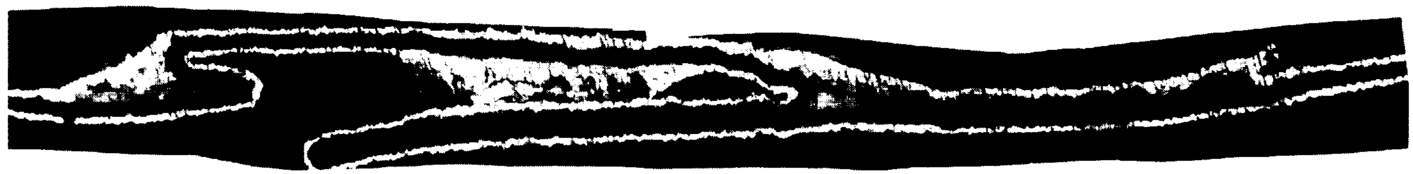
Material	Burst Pressure (mmHg)
Mylar (0.35 mil)	120-150
Aluminum (0.18 mil)	7
GT-15 containing flaws	40-50
GT-15 good quality	120

For the GT-15 material containing flaws, a rapid-popping noise was heard at about 4 mm Hg. These results indicate that a substantial reduction in burst strength occurred. The test results do not permit predicting or estimating the magnitude of the flaw necessary to promote fracture propagation. However, the nature of failure suggests that flaw length was more important than flaw width. Reference 8 presents a detailed analysis of the failure mechanism.

In an attempt to evaluate the structural properties of material containing the defect, three 12.5-foot diameter spheres were fabricated from (1) material containing numerous areas of overlapped aluminum and/or Mylar; (2) material containing defects similar to those of unit 1, but neither as numerous nor severe; and (3) defect-free material. All three spheres were pressurized according to

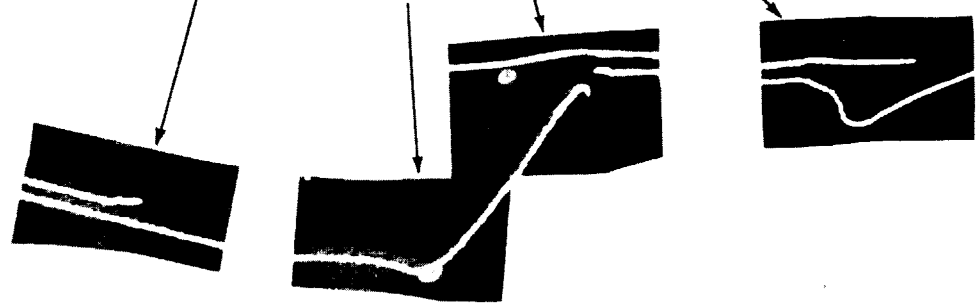
Figure 3-7. Sphere 11 Material Failure

PHOTOMICROGRAPH OF LAMINAR DEFECT
MAGNIFIED: 100X



PHOTOMICROGRAPH OF LAMINAR DEFECT
MAGNIFIED: 500X

PHOTOMICROGRAPH OF LAMINAR DEFECT AFTER RUPTURE
MAGNIFIED: 50X



PHOTOMICROGRAPH OF LAMINAR DEFECT AFTER RUPTURE
MAGNIFIED: 500X

Figure 3-8. Photomicrographs of Echo II Material Failure

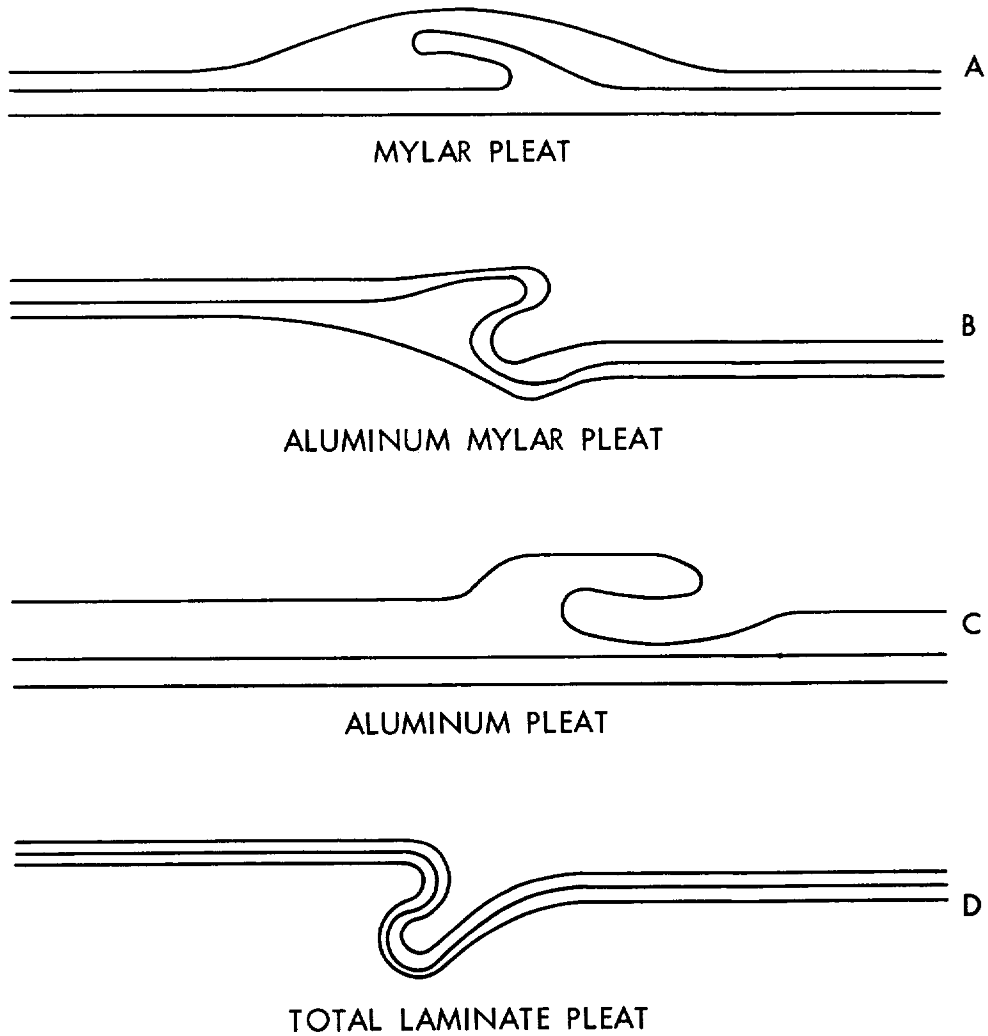
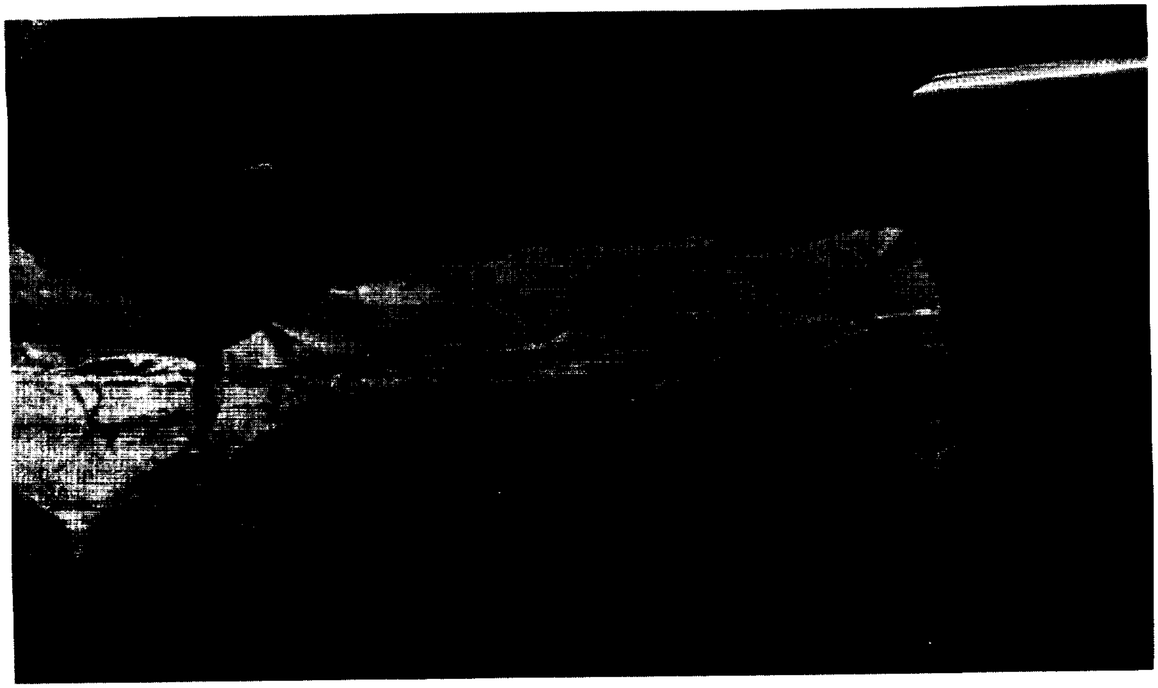


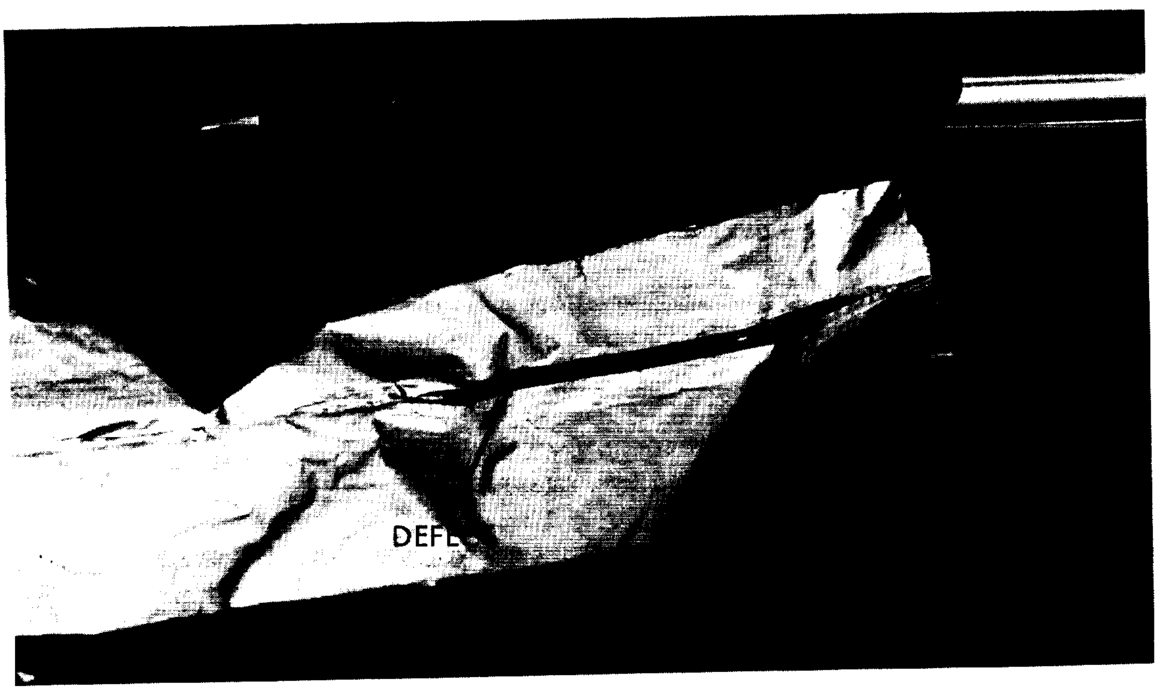
Figure 3-9. Types of Laminate Defects

the following schedule returning to the relaxed condition of 0.1 in. H_2O or 400 psi skin stress for 5 minutes between each level.

Pressure (inches H_2O)	Skin Stress (psi)	Time (min.)
0.743	2800	5
1.274	4800	5
1.964	7400	5
2.973	11200	5
3.557	13400	5
3.68	13900	5
Pressurize to rupture		



(A) MATERIAL DEFECT BEFORE FAILURE



(B) MATERIAL DEFECT AFTER FAILURE

Figure 3-10. Material Defect Before and After Failure

Unit 1 generated popping sounds at 5,065 psi (1.5 inches H_2O). It was determined that this phenomena was caused by the pulling apart of the overlapped defect. The sphere ruptured at 11,458 psi (2.99 inches H_2O) after about 2.5 minutes during the hold at 11,200 psi (2.973 inches H_2O). Failure occurred at one of the larger defects noted. Unit 2 completed the entire test schedule and ruptured at 19,200 psi (5.10 inches H_2O). Unit 3 also completed the entire schedule and then burst at 21,000 psi (5.56 inches H_2O). No popping phenomena was evident during the pressurization of either unit 2 or 3.

The criteria obtained from the failure analysis indicated that a better method of material inspection was required. To facilitate inspection, a general inquiry was made to manufacturers and users of gauges which measure or control thickness of thin material. Five types of gauges were considered: x-ray, magnetic field, contact, B-ray, and air gauges. Initial inquiries requested feasibility of detection, mode of operation, traveling speed, delivery time, and cost. Several gauge manufacturers sent information about gauges which could measure material less than a fraction of a mil thick. Two modes of operation appeared to apply, continuous web scanning by large fixed equipment and stationary spot checking with portable equipment. Table 3-4 lists the manufacturers contacted, types of equipment each recommended, and comments. Defect samples were then sent to four of the most promising suppliers for experimental tests. The detection problem was found more complicated than expected, because plain wrinkles caused by processing operations appeared similar to the overlapping defects. Tests conducted by gauge manufacturers with samples of wrinkles and defect materials were unsuccessful. Wrinkles and defects could be distinguished from good material, but difference between wrinkles and defects could not.

In addition, the following drawbacks were also realized:

a. Continuous web scanning gauges operate at speeds much slower than the relatively slow speed laminating process used to fabricate Echo II material.

b. Radiation type of gauges could not reliably detect the overlapping defect in the Mylar when shielded by aluminum foil.

c. Magnetic field type of gauges could not reliably detect overlapping defects in laboratory tests because of the small difference in thickness.

d. X-ray gauges were designed for piece type check and were not suited to checking large quantities of roll form material. No tests were conducted on GT-15 because existing equipment was not available to handle thin film.

Table 3-4

Thickness-Measuring Equipment

Manufacturer	Measuring Device	Remarks	Approximate Price
General Electric	x-ray gauge Fluoroscope	Spot check, requires application study. Negative results on sample tested.	\$10,000
General Precision	Magnetic field	Continuous scan, 5 ft/min max. speed. Sensing head in contact with material.	\$ 5,000
Ohmart Corp.	β-ray	Continuous scan, 1 to 2 ft/min max. speed. Negative results on sample tested.	\$10,000
Sheffield Corp.	x-ray	Continuous scan, 7 in/min max. 5 month delivery.	
	Air gauge	Metal contact—6 oz/sq in. 2.5 month delivery.	\$2,000 & up
Twin City Testing Corp.	Magnetic field	Spot check—semiportable unit. Negative results on samples tested.	
Unit Process Assembly Corp.	Magnetic field	Spot check—portable unit. Negative results on samples tested.	

e. Contact gauges applied pressure in excess of the yield strength of the laminate and caused creases in the material.

Since no reliable method for material inspection could be developed within the time requirements of the program and with existing equipment, it was decided to improve the visual inspection by personnel trained to identify the overlap defect. Any suspect area which could not be readily identified was subjected to more extensive examination and testing.

3.2.2.4 Equipment Modification and Experimental Lamination

One phase of the material improvement study was concerned with improving the equipment associated with the lamination process. This was done in an attempt to reduce or eliminate shrinkage, castoff, and the overlap defect.

A new hot roll, nip roll, and coating idler roll were built. The exhaust ductwork was also expanded and improved. The lamination and work area was thoroughly cleaned and checked. In addition, several new pieces of equipment were built to facilitate greater control of web tension, web alignment, and material rewind. Experimental laminations were made to evaluate the equipment and associated parameters.

a. Equipment Evaluation—The first device built to control tension was a constant-tension unwind stand. The object of this device was to create a constant but controllable tension on the film as it passed from the unwind stand, over the coating roll, and to the hot roll. The weight of a dancer roll and additional force provided by an air cylinder were supported by the web. Tension was increased by increasing the air pressure in the cylinder. The speed of the variable speed motor on the unwind was controlled by and was proportional to the elevation of the dancer roll. Thus if the motor fed too much web, the dancer roll lowered and the motor speed reduced. The increased web tension returned the dancer roll to near its original position and the motor speed increased. Figure 3-11 is a schematic of the device. Although control of web tension was possible with this device, accurate control at very low tension levels was not attained. During the first test run with the constant tension device, in which laminates were made with web tensions from 0-60 pounds, the coated web wrinkled severely on second pass with zero tension and foil fractures were introduced on second pass if there was zero tension during the first pass lamination. It was recognized that the amount of brake or torque control of the herringbone roller immediately above the hot roll was very critical. The herringbone roller brake was added to the system with a strain-gauge attached (Figure 3-12) to measure the amount

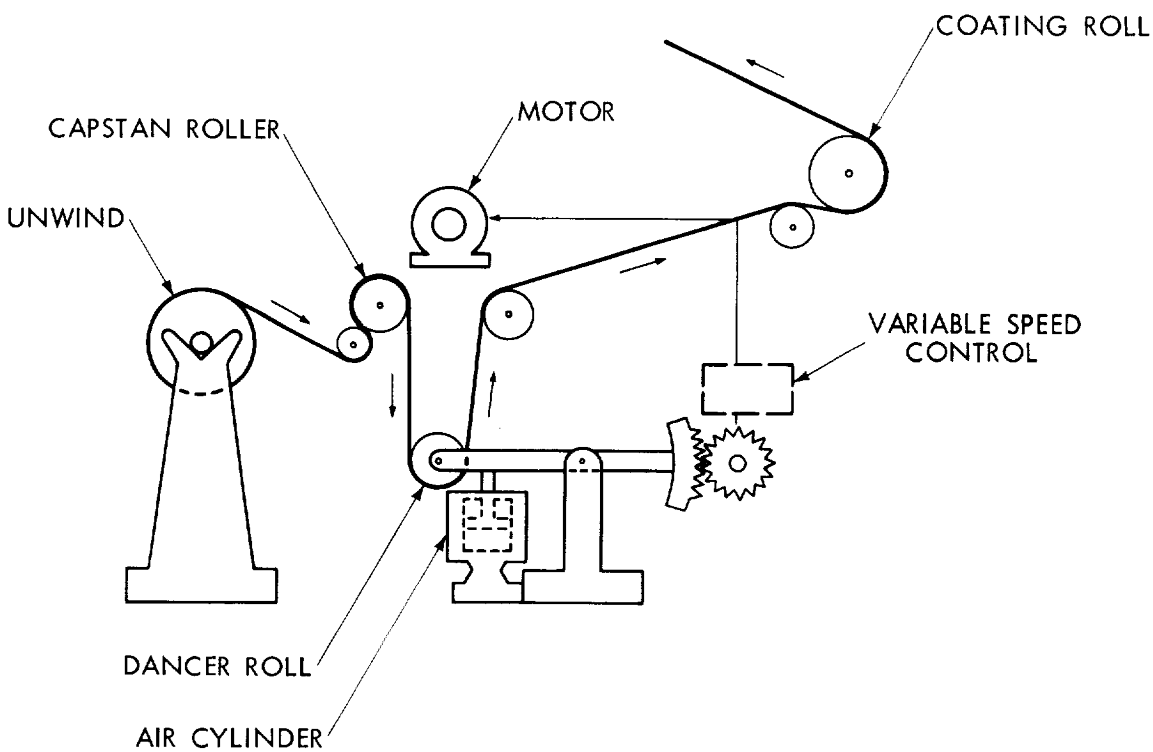


Figure 3-11. Constant Tension Device

of force exerted on the roller by the web and to transmit it to a recording device which indicated relative amounts of tension on the web. The indicating device gave only fair results and required frequent adjustment for zero calibration. It also limited the possible wrap of the Mylar web over the hot roll.

A pair of web spreaders was installed on both sides of the coated web immediately in front of the hot roll. The purpose of this device was to keep the web spread out and to prevent overlapping creases from being laminated into the material. The web spreading device consisted of a pair of offset rollers which worked each side of the film outwards, thereby stretching the film taut. Soon after the experimental run was begun, the web spreaders were moved to a position immediately in front of the coating roll. Although they appeared to hold the Mylar web satisfactorily during the first pass, they had to be removed during the second pass because the edges of the web curled excessively. Later refinements in webbing the machine, placement of spreading rollers, and tension control completely eliminated creases in the web and made the web spreaders unnecessary.

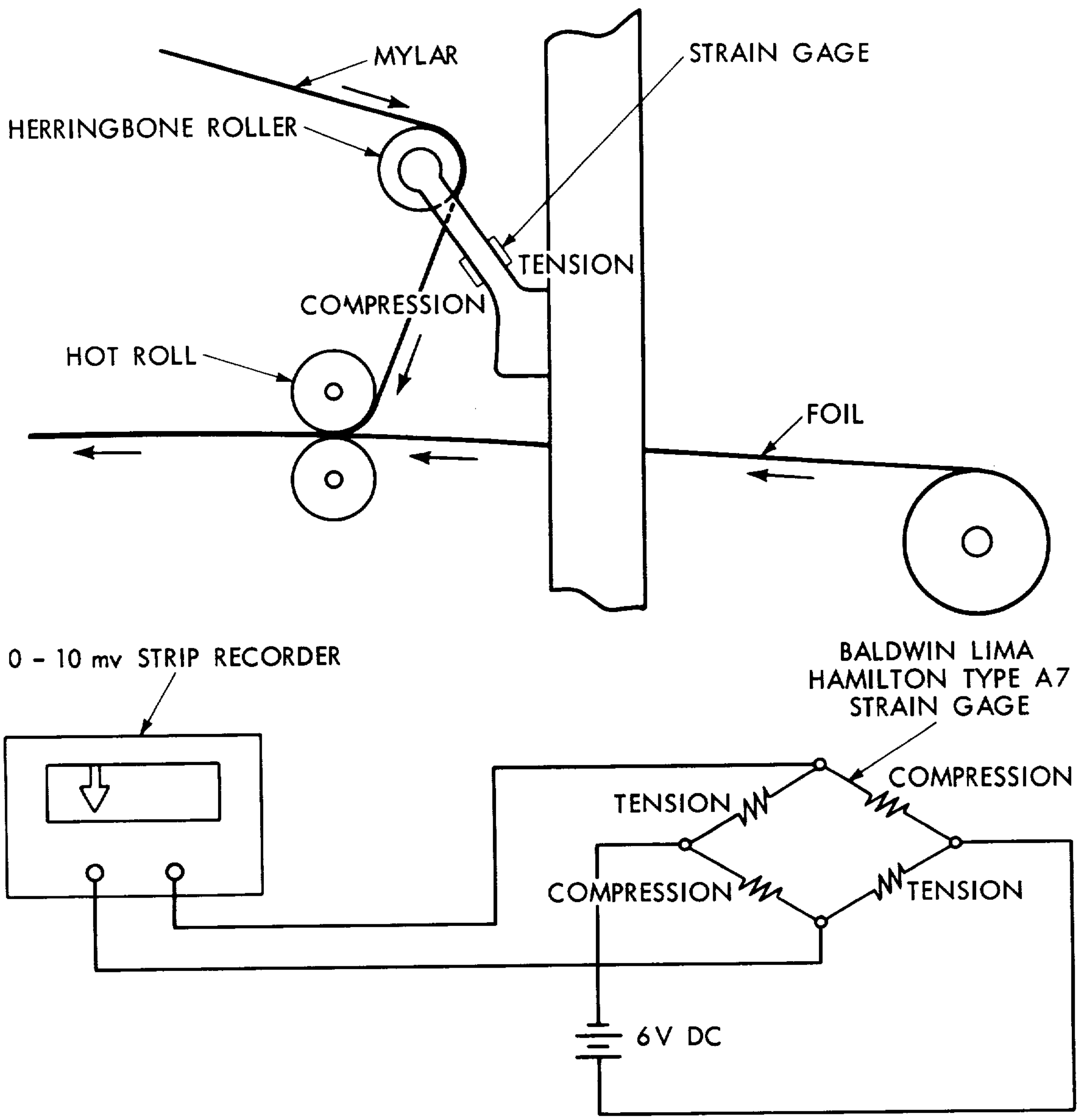


Figure 3-12. Strain Gage Assembly for Herringbone Roller Brake

A new rewind was installed which featured sturdier construction and more sensitive and variable control of the rewind tension. Precautions were taken to assure that the rewind was aligned and that the material could be taken up with minimum tension.

b. Experimental Lamination—A series of laminations were made varying hot roll temperature, web tension, web speed, tunnel drying, rewind tension, hot roll wrap, herringbone brake tension, and solvent in the adhesive. The quality of the laminates was evaluated by in-process tests and by formal laboratory testing of thermal shock, ultimate and yield tensile strength, diaphragm burst, and shrinkage.

The first experimental lamination was run to adjust the equipment, to establish operating parameters for the manufacture of an improved laminate, and to acquaint members of the lamination crew with the proposed procedures for laminating GT-15 material. The Mylar film was coated at speeds of 12, 14, 16, 18, and 20 feet per minute. The air flow in the adhesive drying tunnel was varied from zero to maximum air movement. The air flow was controlled by an exhaust fan, a damper on the exhaust duct, and two hot air heaters. The web was wrapped on the hot roll at 0, 15, 30, 45, and 90 degrees. An occasional delamination was found on laminates made with 30-degree wrap at 20 feet per minute. A wrap of 90 degrees at 20 feet per minute was established as optimum.

A lamination was made varying the hot roll temperature and the web tension. Visual observations indicated that poor quality laminates were produced with low web tension and high hot roll temperature. Quick-look shrinkage tests conducted on the laminates indicated that reduced lamination temperature decreased shrinkage, and reduced web tension decreased shrinkage. A lamination process specification, GT-15-1, was written based on the quick-look shrinkage tests, tensile and diaphragm tests, and visual examination of the laminate. Long-term shrinkage tests on GT-15-1 confirmed the findings of the quick-look tests. Lamination parameters for GT-15-1 were minimum web tension, web speed of 15-20 feet per minute, and hot roll temperature of 300° F.

The second set of experimental laminations was made to define the optimum operating conditions of the equipment, to demonstrate the reliability of the laminate at operational extremes, and to calibrate the herringbone roller strain gauge. Web tension and hot roll temperatures were varied on this run. One of the experiments varied the web tension on the Mylar unwind and on the herringbone roller above the hot roll. No definite conclusions could be drawn from this test except the shrinkage test data supported the previously discovered relationship between reduced tension and reduced shrinkage. Another experiment varied web tension and hot roll temperature yielding the data of Figure 3-13. The laminates made with minimum web tension and low hot roll temperature (230-260° F) showed improved shrinkage characteristics. Another short lamination run was made to firmly establish the operating conditions. In this run about 3,000 feet of laminate was produced at 15 feet per minute web speed, 270° F hot roll temperature, and minimum web tension. Tests

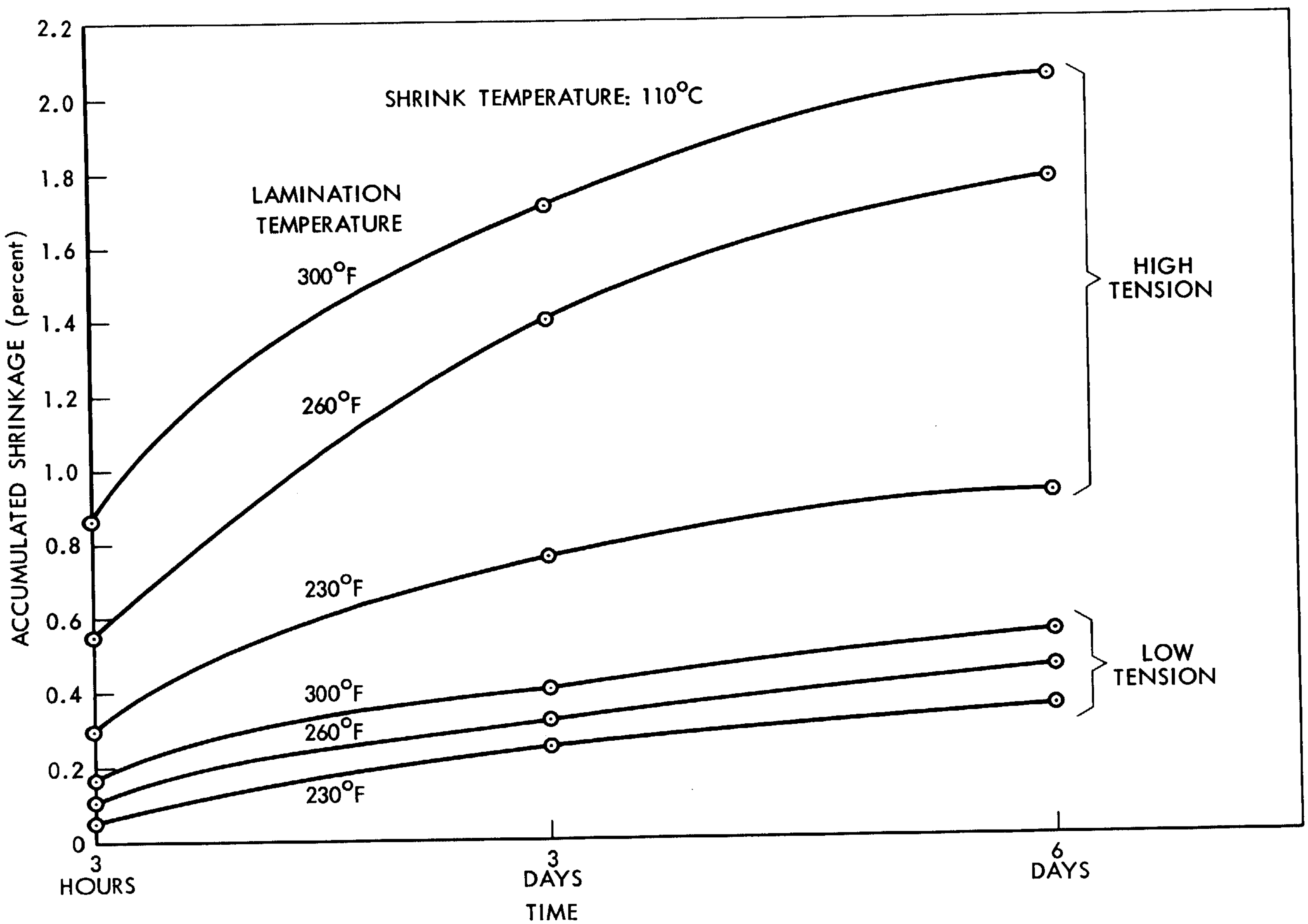


Figure 3-13. Shrinkage vs Time as a Function of Lamination Temperature and Web Tension

performed on this material indicated that shrinkage had been reduced to a tolerable level without endangering the mechanical properties. Additional experiments were conducted in which the temperature of the hot roll was reduced 20 to 40° F below the 270° F planned for production operations. This run was designed to test the structural reliability of the laminate material at lower hot roll temperatures. Limited amounts of delamination were detected and it was concluded that a hot roll temperature of 270° F was realistic. A new lamination process specification, GT-15-2, was then issued providing for laminating at 270° F hot roll temperature, 15-20 ft/min web speed, and minimum web tension. The core size was changed from 3-inch diameter to 6-inch diameter as a result of the castoff reduction study.

The third experimental lamination was based on work performed on a four-ply laminate manufactured for Langley Research Center. This laminate, an unbalanced construction of 0.5 mil Mylar, 0.5 mil aluminum, 0.5 mil Mylar and 0.5 mil aluminum, shrank excessively. The shrinkage (measured after one hour at 150° C) of the laminate was decreased by a factor of ten owing to a lamination technique in which the aluminum foil instead of the Mylar film was coated with adhesive and passed over the hot roll. The purposes of the third lamination were to determine the feasibility of coating the foil, to produce a sample for testing purposes, and to develop techniques and operating parameters for manufacturing production quantities of the laminate. The material produced during this lamination was designated GT-15-3. Lamination parameters consisted of 300° F hot roll temperature, 14-16 ft/min web speed, minimum web tension and use of 6-inch diameter material cores.

The first samples of the GT-15-3 laminate were made without difficulty, although their appearance left much to be desired. The samples were tested for shrinkage, castoff, ultimate and yield strength, elongation, delamination, and burst strength. The immediate results were encouraging and therefore work was started immediately to develop techniques of laminating orbital quality material.

Initially the effort was concentrated on adjusting machine variables, i.e., hot roll wrap, adhesive drying, web temperature (solvent evaporation and the corresponding heat loss), and nip pressure. No combination of variables improved the quality of laminate to a satisfactory level. In addition, small blisters appeared in the laminate and were aggravated by heat treating. The presence of the blisters was difficult to establish on freshly laminated material, though they were readily discernable after the material had been exposed to a temperature of 110° C for 3 days.

The blisters appeared to have originated in hairline wrinkles which were introduced into the foil web between the coating wheel and the hot roll. Generally, the blisters appeared only in the first pass side of the laminate and were concentrated more heavily towards the edge of the web. Precautions were taken to assure even adhesive coating of the web and constant tension and pressure across the hot roll and nip roll, but the blisters continued.

To preclude the possibility of the blisters being mechanically trapped within the hairline wrinkles in the coated web, a web carrier was provided to carry the coated foil to the hot roll. A continuous belt was provided that picked up the foil immediately after it was coated and carried it through the drying tunnel. It was felt that this technique might prevent the foil from being mechanically wrinkled by passing over rollers; however, it did not eliminate blister formation.

Small blisters were observed on portions of the material sampled for testing. Subsequent metallographic examination of these small surface imperfections revealed that they represented areas of plastically deformed aluminum film resulting in the formation of a hollow void between the metal and Mylar. The presence of entrapped solvent vapors during the laminating process explained the development of these surface blisters. The heat-treating process caused expansion of the entrapped solvent providing enough pressure to deform the aluminum. The biaxial stress results have shown that invariably these internal voids become favorable sites for crack initiation because the mechanical discontinuity acts as a stress raiser. Preferential alignment of these surface bubbles transverse to the rolled direction could prove deleterious if the individual cracks link up to develop the critical length crack necessary to promote premature failure. Therefore, since no remedy could be generated for the formation of the blister condition, the lamination of GT-15-3 was discontinued. Material for spheres 16, 17, and 18 was laminated as GT-15-2.

3.2.2.5 Shrinkage Reduction and Heat Treatment

Studies of shrinkage were undertaken to minimize the effect of exposure to a hot spot temperature of 110°C. This temperature was derived from thermal balance calculations of the sphere. In early studies, attempts were made to correlate the shrinkage rate at 150°C with that observed at 110°C in the hope that accelerated tests could be run on the laminate. Comparative data, however, indicated little hope for such a correlation, at least without extensive studies of various materials. For this reason in the experimental studies emphasis was placed on reducing the shrinkage during 3 hour and 3 day exposures to 110°C. For expediency the tests were conducted on "as laminated" material.

It was found that the shrinkage of the Alodine coated materials was much more severe than that encountered in the uncoated samples. It is theorized that this occurs because the cleaning and Alodine coating operations cause etching of the laminate surfaces, and the aluminum structure is thereby sufficiently weakened to allow the residual stresses in the Mylar to cause the laminate to shrink appreciably greater amounts. This theory is confirmed by the data presented in Table 3-5, which summarizes the observed 3- and 6-day shrinkage of rolls of the laminate without Alodine coating, and of gore samples that were Alodine coated, inked, and heat treated. Were the shrinkage of the laminate unaffected by the Alodine coating, the shrinkage observed in the roll samples after 6 days should correspond to that of the heat-treated laminate after 3 days. It can be seen that the shrinkage of Alodine coated material after 3 days is higher by a factor of 2-1/2 than non-Alodine coated material after 6 days.

Table 3-5

Percent Shrinkage of GT-15-2 Laminates

Laminates	Shrinkage (%)	
	3-Day	6-Day
Roll samples, not Alodine coated	0.12	0.22
Gore samples, Alodine coated	0.55	0.64

To demonstrate the nature of shrinkage, samples of GT-15-2 laminate, both Alodine coated and heat treated, and as-laminated, were cut, marked, and the aluminum between the gauge marks removed by etching in sodium hydroxide ($NaOH$). On exposure to 110°C almost all the shrinkage occurred in the first 3 hours. The fact that there was essentially no change due to etching alone indicates that shrinkage is not due primarily to locked-in lamination stresses. A companion experiment indicated that while Alodine coating does not cause aluminum foil to shrink, the Alodine coated foil will shrink when heated 72 hours at 110°C.

Shrinkage of GT-15 laminates is caused by the tendency of the Mylar (oriented polyethylene terephthalate) film to shrink when exposed to elevated temperature.

This tendency is resisted by the aluminum. The opposing forces of thermal expansion of both the aluminum and Mylar is counteracted by the tendency of the Mylar to shrink.

a. Tendency of Mylar to Shrink with Heat—DuPont personnel noted, and the literature confirms, that the shrinkage of unrestrained Mylar varies directly with the temperature to which it is exposed. Shrinkage is an irreversible phenomena. Once a sample of film has been exposed to some elevated temperature and has shrunk, it will not shrink further unless again exposed to a higher temperature. This contrasts to the behavior of oriented organic glasses reported by Cleereman, et al. (reference 10). Their data, obtained on another polymer system, showed continuing shrinkage, but that extremely high activation energies were associated with the change. It may be that the Mylar system involves such high activation energies that the tendency to shrink is eliminated in a very short period of time. It is interesting to note, however, that in the present investigation samples of plain Mylar showed continued shrinkage after the initial short term exposures to 150°C. Similar results at 110°C were also obtained on Mylar which had been passed over a hot roll at various temperatures—a treatment recommended by duPont to eliminate shrinkage.

   In addition to shrinkage, heat also affects other properties of the laminate. According to the duPont literature the effects of long-term exposure to elevated temperatures should not be great since 250 hours at 150°C is required to lower the tensile strength from 22,500 to 19,000 psi. This effect would be accompanied by a drop in elongation from 145 to 140 percent. It is recognized that the processing conditions for Mylar should be kept below 200°C, for if Mylar is heated to 220°C for 30 minutes the film loses some of its toughness and if heated to 235°C for 30 seconds the film becomes brittle and shatters. When loosely wound on a roll and heat treated 72 hours at 110°C, 0.5-mil Mylar shrinks 0.26 percent after 3 days and 0.35 percent after 6 days.

b. Other Causes of Shrinkage—Shrinkage may be caused by other factors. For instance, the hydroscopic coefficient of expansion for Mylar is 11 x 10^{-6} inch/inch/percent relative humidity. Since a 50 percent change in relative humidity may occur between room conditions and a 100°C oven, this alone may cause shrinkage of 0.55 x 10^{-3} inch/inch or approximately 0.06 percent.

   Another contributing factor is the coefficient of expansion of Mylar, which is 1.5 x 10^{-5} inch/inch/degree Fahrenheit in the temperature range of 70 to 120°F. Thus, cooling from the 270°F laminating temperature to a room temperature of 70°F will introduce a shrinkage of 0.30 percent. This effect is greatly reduced by the offsetting thermal expansion coefficient of aluminum of about 1.2×10^{-5} inches/inch/degree Fahrenheit.

c. Test Methods—Shrinkage tests were performed on Mylar before lamination, and on GT-15 material before and after heat treatment. Samples were taken from the beginning of each roll of Mylar, the beginning and end of each roll of GT-15 material, and from orbital quality gores. Measurements were made on specimens cut in the machine direction and in the transverse direction until data were established which indicated residual shrinkage to be much lower in the transverse direction. Thereafter, measurements were made only on machine direction specimens.

Five specimens, 14 inches long and 1 inch wide, were cut from each sample. On each specimen, two scribe lines were placed approximately 10 inches apart. By means of a glass plate (for attachment of the specimen), a 60 power calibrated scope, and a vernier height gauge, the exact distance between scribe lines was measured with a 200 gram load attached to the specimen. The specimens were then subjected to 100°C for various periods of time. Residual shrinkage was measured and reported in percent of shrinkage for each period.

d. Heat Treatment Studies—After various preliminary heat treatment tests it was decided that a 72-hour exposure of GT-15 laminate to 110° ±3°C would eliminate the major shrinkage. The temperature was selected on the basis of studies carried out at that temperature, as it represented the calculated hot spot on an Echo II sphere. An exposure of 72 hours was chosen as a compromise between a major elimination of shrinkage and time considerations. Experiments indicated that any great increase in either time or temperature would cause some loss in physical strength or toughness of the GT-15. It was necessary that the treatment be carried out with unrestrained material to allow freedom for the relief of stress. The data shown in Figure 3-14 indicate that extended time or very high temperature caused some loss in physical properties. The drop in physical properties indicated that the temperature should probably be less than 120°C. It was determined that the maximum temperature should be 113°C.

Generally it appeared that the GT-15-2 which had not been Alodine coated shrunk one-third as much in 3 hours as it did in 3 days and shrunk one-half as much in 3 days as it did in 6 days. Strictly comparable data was

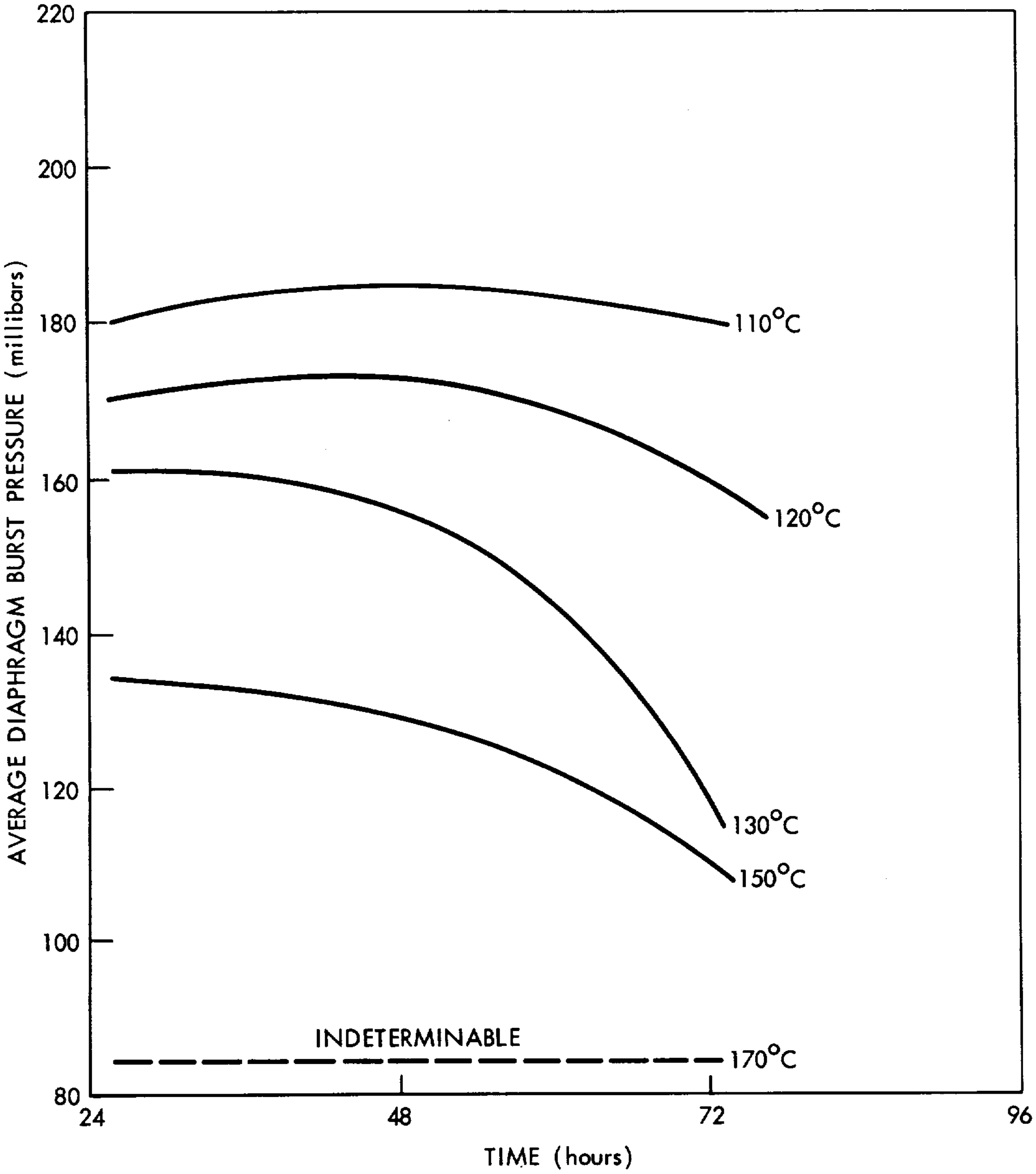


Figure 3-14. Degradation of Laminate at Elevated Temperatures

not available for Alodine coated material. Table 3-6 shows the effect of Alodine coating. These samples represent roll samples which were not Alodine coated and comparison samples which were Alodine coated. It can be seen that chemical action is responsible for the difference.

Shrinkage tests at 150°C for 1 hour were carried out in an attempt to establish a correlation with behavior at 110°C. The results in Table 3-7

Table 3-6
Comparative Shrinkage of GT-15-2 with
Alodine Coated Non-Heat Treated GT-15-2
(percent of shrinkage)

Sample	3 Hours	3 Days	4 Days	6 Days
Roll 456-1 As-laminated	0.17	0.36	0.45	0.55
Roll 456-1 Alodine coated	0.61	0.88	0.94	
Roll 457 As-laminated	0.12	0.27	0.30	0.40
Roll 457 Alodine coated	0.66	1.02	1.13	1.27

Table 3-7
Comparative Shrinkage of GT-15
Laminates at 110 and 150 Degrees C
(percent of shrinkage)

Sample		1 Hour at 150°C	3 Hours at 110°C	3 Days at 110°C
96-38-1	MD	0.14	0.10	0.49
	TD	0.06	0.08	0.19
96-38-2	MD	0.08	0.04	0.25
	TD	0.02	0.03	0.23
96-38-3	MD	0.08	0.06	0.27
	TD	0.05	-0.01	0.13
96-38-4	MD	0.09	0.09	0.30
	TD	0.03	0.02	0.12
96-38-5	MD	0.04	0.07	0.03
	TD	0.08	0.01	0.08
407-A	MD	0.10	0.12	0.40
(GT-15)	TD	0.06	0.00	0.22

NOTE: MD, machine direction; TD, transverse direction show that 1 hour at 150°C does not produce appreciable shrinkage in GT-15 laminates and although the results may compare with 3 hours at 110°C they do not even approach the 3-day results. This behavior is attributed to the effect of the aluminum, since plain Mylar at 150°C shrinks about 2 percent in one-half hour and only slightly more thereafter.

A number of large-scale experiments were conducted to confirm laboratory studies of heat treatment effects. Some of these are summarized below:

(1) In a test for castoff, a Mylar roll was reversed in orientation. The resulting laminates had castoff in opposite directions indicating that laminator alignment was probably not a major factor in castoff.

(2) Full gore lengths and some shorter pieces of material were carefully measured, heat-treated 72 hours at 110°C, and measured again. The results agreed satisfactorily with laboratory values.

(3) Severe shrinkage occurred in the Mylar edges when GT-15 or X-91 material with exposed bands of Mylar was heat treated. This effect confirmed the restraining power of the aluminum and indicated shrinkage in Mylar approximately an order of magnitude larger than that of the laminated. In some of these cases the Mylar had the same temperature exposure as the rest of the material.

e. Production Heat Treatment—Precision temperature-controlled ovens of Environ, Inc., Minneapolis, Minnesota, were used for production heat treatment of GT-15 laminates. The material in 240 foot lengths was loosely wrapped on Mylar protected cardboard cores and then covered with one-half mil Mylar overwrap. The ovens were provided with steel racks so that each gore could be suspended on a piece of steel tubing through the core. Studies of temperature distribution within the oven indicated control to within ±1.5°C so that a range of 110-113°C was used. Experiments conducted on temperature within the loosely wrapped gores on cores in the oven showed that thermocouples in the inside of the gore and outside came to oven temperatures within 3-1/4 hours (Table 3-8).

3.2.3 SPECIAL LAMINATIONS

In addition to the basic laminate, special laminations were made for the reinforced gores and for the end caps. Reinforced gore material (X-91) was prepared by laminating an additional layer of Mylar 0.5 mil thick to Alodine coated GT-15 material.

Table 3-8

Temperature History for GT-15 in Environ Oven
(in degrees Fahrenheit)

Time	Roll No. 1 Bottom of Oven		Roll No. 2 Top of Rack	
	Outside	Inside	Outside	Inside
October 2, 1963				
1830	95	78	109	88
1845	127	100	130	95
1900	143	116	149	115
1915	169	140	163	135
1945	192	167	193	164
2000	207	184	210	183
2030	218	206	221	206
2100	225	217	228	216
2130	228	223	230	223
2145	231	229	232	229
2200	232	231	232	231
2330	232	231	232	231
October 3, 1963				
0800	233	233	234	233
0930	233	233	233	233
1400	228	228	228	229

Temperature at heat source exhaust 228° F

Mylar covered thermocouples near heat source on rack 228 - 232° F (1/3 mil Mylar)

Temperature near center of gore stack 228 - 233° F

Material used for the end caps was designated GT-16. This material consisted of a lamination of two layers of 0.18 mil aluminum to a layer of 1.0 mil Mylar. The lamination was made by a process similar to that used for GT-15. Therefore the GT-16 material possessed the properties of GT-15 with respect to thermal shock resistance, delamination, and the other characteristics, but possessed about three times the ultimate strength of the GT-15.

3.3 THERMAL CONTROL

Control of temperature in the Echo II satellite was highly important for operating the beacons and the inflation system as well as for preventing extreme temperature exposure of the material and seals.

At the outset of the program the need for thermal-balance coating was recognized; it was assumed the coating would consist of ink printed on the surface of the laminate before fabrication. Research and studies made on the applicability of commercially available inks disclosed extreme difficulties in printing the ink coating, the need for stability in the high vacuum of ultraviolet exposure of space, and the necessity of keeping the balloon weight to a minimum. It became apparent that a more sophisticated solution would be required.

Materials to provide thermal balance with minimum additional weight and minimum danger of blocking, cracking, and change of characteristics under space conditions were studied. Achieving thermal balance required a uniform coating of high emissivity (ϵ) on the interior surface and a uniform coating with a low absorptivity-emissivity ratio (α/ϵ) on the exterior surface.

An inorganic conversion coating, Alodine 401-45, deposited with materials supplied by Amchem Corporation was found to provide suitable absorptivity and emissivity with a weight increase of about 20 pounds. This coating effectively increased the emissivity from about 0.04 to 0.18 and also increased the absorptivity from about 0.18 to 0.32. The ratio on the exterior was then about 1.78.

To supplement the Alodine, a coating of Higgins black waterproof ink No. 44 was applied over the Alodine on the interior surface. This changed the interior emissivity from approximately 0.18 to 0.6-0.8.

In certain reinforced areas need existed for other controls; these were achieved by the use of laminated Mylar on the interior of the reinforced gores, and the application of Vita-Var coated X-15 to the surface inside of the beacons. Half-mil Mylar laminated to Alodine coated X-15 yielded an emissivity of 0.5 and the Vita-Var coating had an emissivity of approximately 0.8.

A detailed discussion of the Echo II satellite thermal control system can be found in reference 11.

3.3.1 ALODINE COATING

Early samples of Alodine coating made at the Amchem laboratories using Alodine 401-41 were found unsatisfactory for full-scale processing because of formation of a precipitate in the solution. It was then decided to use Alodine 401-45, which has similar characteristics as 401-41. After an initial sharp rise the α/ϵ ratio steadily drops as the coating weight increases. Originally the coating weight was projected to be about 150 milligrams per square foot. This was later increased to 184 ±3 mg/ft^2 as the requirements for the thermal balance changed.

In the Alodine coating process a small amount of the aluminum on the surface is dissolved and causes precipitation of a complex aluminum chromium phosphate fluoride, the exact composition of which is not defined. Control of the process requires that concentrations of aluminum, hexavalent, and trivalent chromium, phosphate, iron, and fluoride ion also be controlled. The precise control required for this program represented a new realm in accuracy, as previous uses for Alodine coatings had been primarily directed toward surface priming for adhesion of paint and lacquer.

It was determined during the Alodine coating operations that coating weight was markedly affected by the vigor of the air agitation used. A report issued by Amchem Laboratories on December 28, 1961, indicated the magnitude of the effect and suggested bath recirculation as a method for control of coating weight. Their findings indicated a 100 to 200 percent change in coating weight for various amounts of bath recirculation and air agitation. The data indicated as well the discrepancy in coating weight between the top and bottom of samples tested. Later in the program minimum air circulation with respect to coating weight was used to minimize the spread between top and bottom of the web.

The Alodine coating equipment was laid out as shown in Figures 3-15 and 3-16 and processing was arranged to provide unwind, cleaning, Alodine coating, water wash, deionized wash, and drying before rewind.

The Alodine coating was applied in a continuous roll to roll process, with the operation controlled to give a coating weight, as determined by nitric acid stripping, of 184 ±3 mg/ft^2 on the exterior surface, and 150 ±50 mg/ft^2 on the interior surface. The coating rate, or amount deposited, was dependent on web speed (a constant of 7 feet per minute), bath concentration, air agitation of coating bath, and bath temperature. The concentration of chemicals in the coating

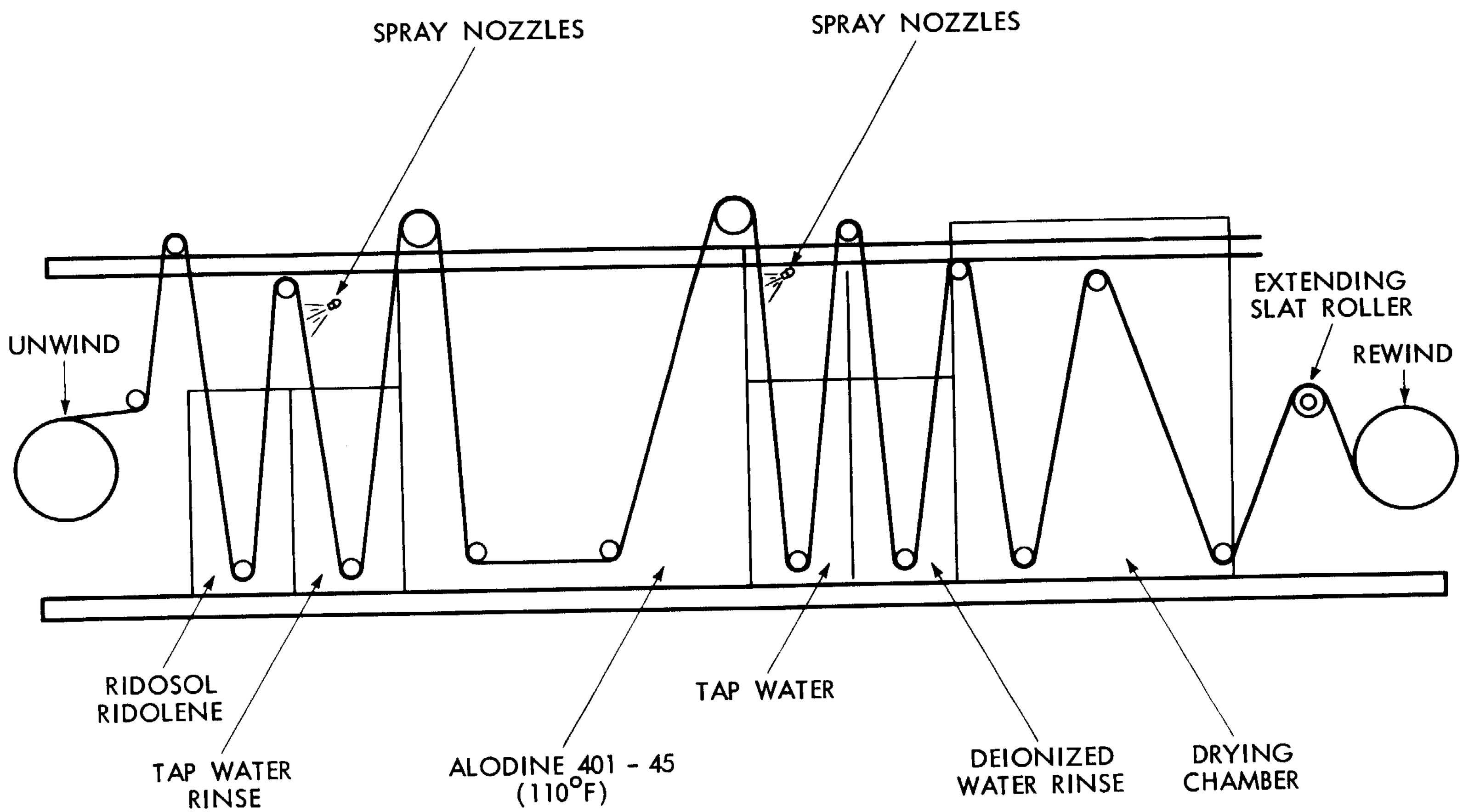


Figure 3-15. Schematic Diagram of Alodine Coating Operation

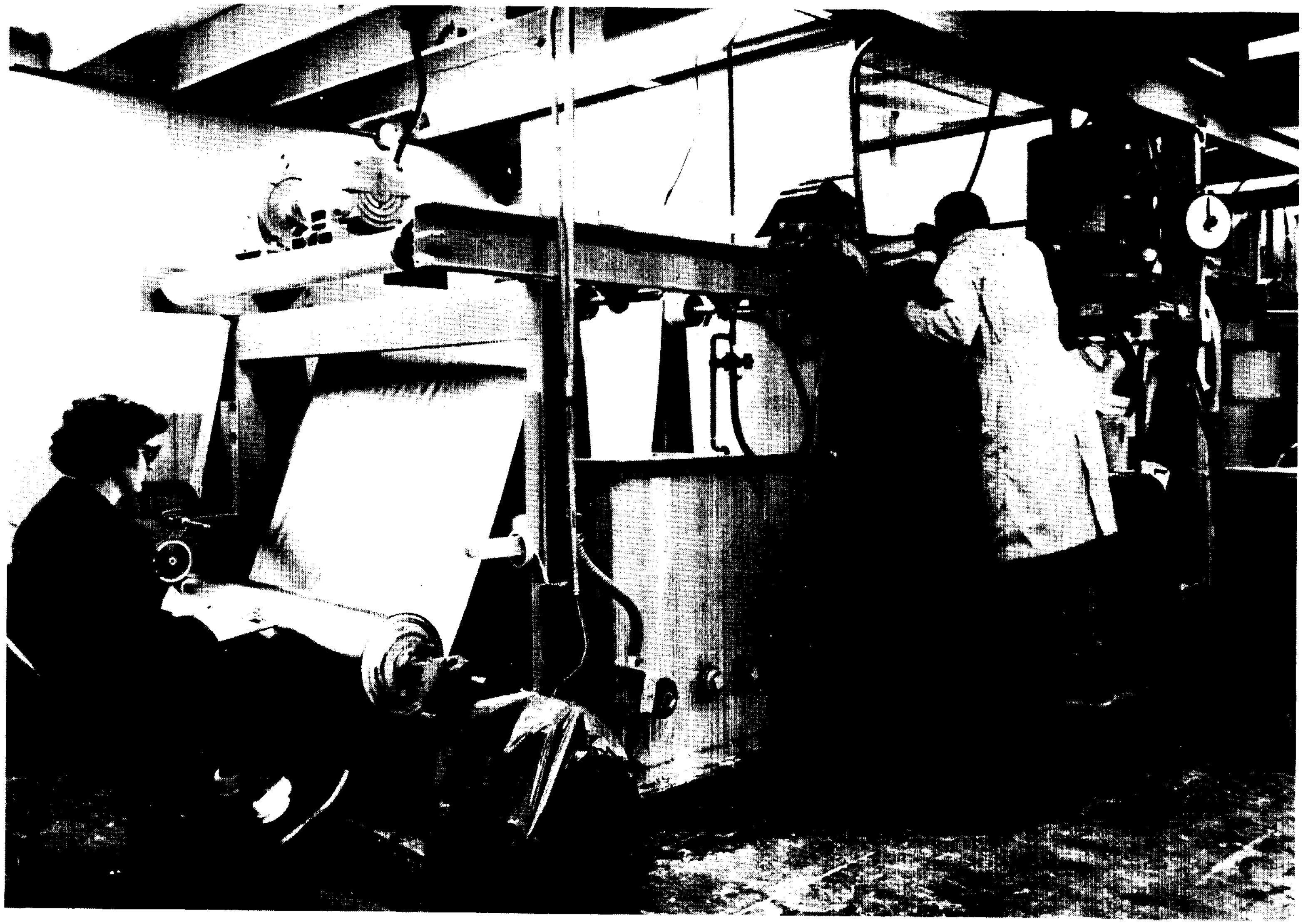


Figure 3-16. Alodine Coating Operation

bath was maintained by close control of replenishment rates on the Alodine No. 401-45 and deionized water. Constant volume of coating bath was predetermined by use of an overflow stand pipe leading to the waste disposal and treating system. This resulted in much less variation in coating weight from sample to sample than had been experienced during previous runs.

During the process, gore lengths and sample numbers were marked every 240 feet on the top side of the laminate to identify the gores and test samples. Two samples were taken from each end of every gore length at the center of the web; one sample area was used for coating weight determination (3 pieces 6 in. by 6 in. for top coating and one piece 6 in. by 6 in. for bottom coating weight), the second sample area was used for absorptivity and measurements. It was necessary to sample the coated material after the deionized water wash and before drying as drying sets the coating so firmly that it cannot be removed with the dilute nitric acid employed in coating weight tests. The process of removing samples from the center of the web during Alodine coating caused a great deal of wrinkle formation both in that process and in the subsequent machine inking operation.

Calculations of the weight added indicate that approximately 42 pounds is added to the sphere weight and that approximately 21 pounds of aluminum is dissolved in the process of cleaning and Alodine coating, resulting in a net increase of 21 pounds. The specific gravity of the coating has been determined to be 2.232. For the coating weight of 184 milligrams per square foot, the thickness of the coating is 3.5×10^{-5} inch.

In addition to providing the proper thermal balance, the Alodine coating has effective surface properties for the application of adhesives used in making seals and of ink for additional thermal control. Studies by weight loss in vacuum and at high temperature and through extraction with anhydrous methanol indicated the presence of small amounts of water in the Alodine coating, which contributed to the initial inflation and deployment of the spheres. The water content of the Alodine coatings was also determined by soaking the material in anhydrous methanol and then tritrating by the Carl Fisher method. These experiments indicated approximately 0.2 percent moisture in the Alodine coated material.

It was also demonstrated that the Alodine coating and ink led to some adhesion by benzoic acid when it was used as an inflatant. This effect was overcome by the incorporation of a melamine dye into the benzoic acid.

3.3.2 INK COATING

The Higgins No. 44 black waterproof ink used to supplement the Alodine coating to accomplish thermal balance was applied to the internal surface of Alodine coated gores by various methods during the program. At the outset, when it was determined that an internal ink coating would be required, the ink was applied first by spraying and later by brushing. The reverse roller coating method was incorporated as techniques were developed and was used during the latter portion of the program. The 64-inch and 84-inch laminators were used for the inking process.

The problems associated with applying the ink lay primarily in obtaining consistent wetting of the surface and in the formation of small crystals under certain drying conditions. The crystals were analyzed and found to have no effect on the volatile substance in the material and were shown to be nonblocking. When properly applied the ink coating was uniform and offered no flaking or cracking problems except in areas where unwarranted thicknesses were used. Thickness of the ink coating applied by rollers was controlled by a combination of web speed, coating roller speed, and dilution of the ink.

The reverse roll coating method initially involved a solution of 80 percent Higgins No. 44 ink and 20 percent distilled water, with 1/2 percent ammonia added, combined with a material web speed between 8-1/2 and 20 feet per minute and a coating roll speed of 22.5 to 23 rpm, which yielded a dry coating weight of 12-15 pounds for the complete sphere. Later in the development program of the sphere, requirements for a higher emissivity on the interior surface necessitated heavier ink coating weights. To achieve this, the ink was applied full strength without addition of distilled water or ammonia. The web speed was maintained at 15 $\pm$4 feet per minute with a coating roll speed of 5-9 rpm. This yielded a coating weight of 17-19 pounds. The coating weight deposited was determined from square foot samples taken between gore lengths, weighed to the nearest 0.01 gram before and after stripping the ink with a solution of ammonia and distilled water.

3.3.3 THERMAL BALANCE OF REINFORCED GORES

The reinforced gores used for the attachment of the beacons and solar cells were made by laminating half-mil Mylar to X-15 laminate. Since this operation was carried out before ink coating, a thermal balance coating was required to avoid a hot or cold spot. It was found that the Mylar increased the emissivity from 0.18 to approximately 0.5.

Special Vita-Var patches were made for application immediately below and around the beacons. This white diffused coating had a high emissivity at the temperature anticipated for the beacons as well as a high reflectivity for solar radiation. The Vita-Var patches consisted of GT-15 laminate material coated with approximately 5 mils of Vita-Var No. 15966 PV-100 material. These thermal balance sheets were applied to the balloon surface immediately before beacon installation.

3.4 GORE CUTTING

3.4.1 STACK AND WOLF CUTTER METHOD

Gore cutting operations for spheres 1 through 15 were carried out using the stack and wolf cutter method. This method consisted of four basic operations:

a. Material Layout—The Alodine ink-coated laminate was dispensed from a roll onto the cutting table in 220 foot lengths. Gores were laid with the unwind fixture from south to north only, with the Alodine side facing up to keep the gores oriented. For identification, the Alodine sample numbers were written on the end of the gore and on the laboratory test samples. Approximately 20 to 50 gores were layed in a stack and each was held in position by tape on the selvage edges.

b. Pattern Layout—A 10-mil Mylar full-size contour pattern was used for marking the cut line to guide the wolf cutter. The pattern, rolled up from each end to the equator, was placed at the center of the stacked gore-lengths and carefully rolled out. A surveyor's transit (Figure 3-17) was used to align the pattern on the table and numerous 2-pound weights held the pattern in position. The pattern outline was then traced on the top gore of the stack with a ballpoint pen. Scribe punches were driven through all layers about every 2 feet along the edge for alignment marks. The pattern was then rolled up from each end towards the equator and removed from the table.

c. Tailor Cutting—Cutting of the stacked gores was performed by a technician using an electrically operated wolf cutter (Figure 3-18). The technician guided the cutter by the outline marked on the top gore. The laboratory samples and test seal material samples were cut from each end of the gore selvage edge.

d. Gore Pick-Up—After quality control inspectors had measured the top gore for width accuracy (±0.040 inch) the gores were individually rolled onto preweighed polyethylene covered cores. Both sides of the gores were inspected for defects during the rerolling process. The gore, after being weighed, was wrapped for protection in red polyethylene and identified by marking the gore number on the cover. The two pieces of material for sample seals were also identified with the gore number and

Figure 3-17. Transit Method of Gore Pattern Layout

Figure 3-18. Wolf Cutter Method of Gore Cutting

wrapped with the gore to ensure identification and for later use in seal sample preparation.

3.4.2 RAIL GUIDED CUTTING METHOD

Surface smoothness of the Echo II sphere depends largely on two fabrication operations—gore cutting and gore sealing. Gore cutting is important since the sealing tolerances depend largely on the edge accuracy of the cut gores. Past cutting operations, as previously described, consisted of spreading the gores on a flat surface, laying a pattern on top, marking the pattern outline, removing the pattern, and following the outline with a hand controlled power cutter. This method introduced errors since the pattern, marking, and hand cutting compounded deviations from the theoretical gore outline. The basic disadvantage of this method was that the accuracy of cutting depended on human skill. In addition, the marking of alignment points, by piercing the material with a sharp pin about 1/8 inch from the edge, sometimes led to tearouts on the edge and larger tears in the gore during sealing.

To overcome these difficulties, a rail guided cutter (Figures 3-19 and 3-20) was developed under the quality improvement study (NAS 5 3243 Mod 8) and was used in fabricating spheres 16, 17, and 18. The equipment consisted of 1/4 by 1/2 inch aluminum rails attached to the top of a sturdy wooden fabrication table 60 inches wide by approximately 250 feet long. The rails provided the gore outline as shown in Figure 3-21.

The cutting sequence consisted of four basic operations:

a. Material Layout—A gore length of material was laid over the pattern and fastened to the table with double-sided pressure sensitive tape on the selvage edges.

b. Cutting—Manually operated rotary cutters (Figure 3-22) were then placed opposite one another at one end of the pattern. The cutters were then simultaneously manually driven, guided by the rails, along the pattern. It was imperative that the cutters operate together (Figure 3-23), since cutting one side of the gore ahead of the other would release tension on the gore widths.

c. Increment Marking—The increment marks were then applied to the cut gore by striking the laminate with an automatic center punch, modified with a rubber pad, over holes drilled into the guiding rails. The marking tool provided a small permanent indentation in the laminate which was retained throughout the fabrication process.

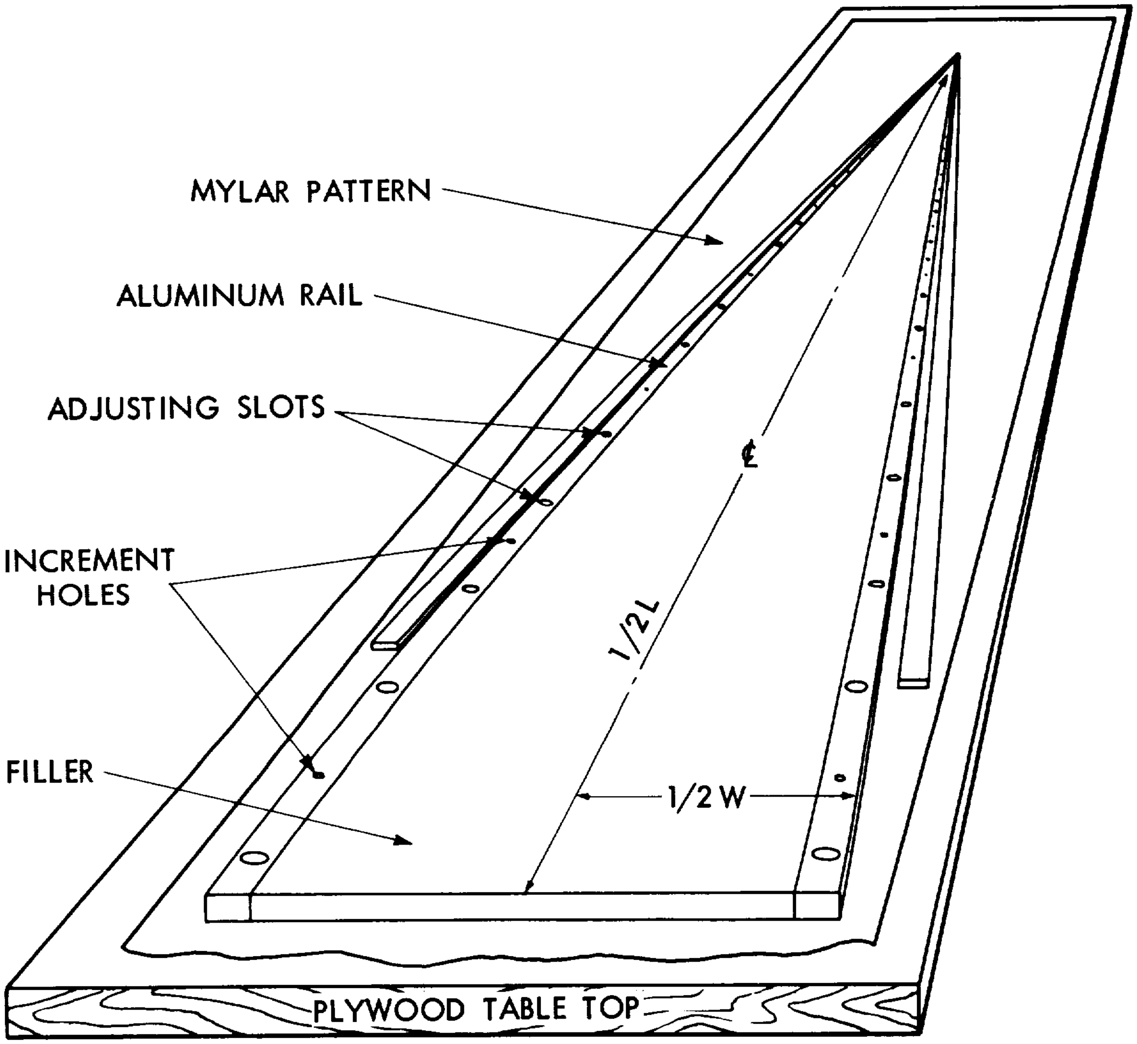


Figure 3-19. Rail Guided Cutting Table

d. Inspection—Each gore was then given 100 percent visual inspection for inherent material defects caused during the cutting operation.

The individually cut gore was then rolled onto polyethylene covered cores and weighed.

The rail-guided cutting method had several advantages over the stack and wolf cutter method. These include: (1) an adjustable pattern, (2) compact hand-powered cutters, (3) inexpensive replacement cutter blades, (4) mechanical guide for cutting, (5) one pattern layout with occasional adjustment, (6) reduced number of gore measurement checks, (7) more uniform gore edge (eliminating tear starting points), (8) improved butt joint alignment for sealing, (9) tear-proof

Figure 3-20. Rail Guided Gore Cutting Operation

NOTES:

DIA. OF SPHERE = 135'
NO. OF GORES IN SPHERE = 106
L = ONE QUARTER OF THE CIR. OF THE SPHERE
N = NUMBER OF GORES IN SPHERE
Q = RADIANS
R = RADIUS OF SPHERE
S = GORE SEGMENTS FOR PLOTTING PATT.
1/2 W = ONE HALF THE WIDTH OF GORE AT "S" POINTS
W = WIDTH OF THE GORE OF W (AT WIDEST POINT) x N = CIR. OF THE SPHERE

FOR SPHERES FROM 0' TO 30' DIA USE EVERY THIRD RADIAN TO CALCULATE "S"
FOR SPHERES FROM 30' TO 60' DIA USE EVERY SECOND RADIAN TO CALCULATE "S"
USE ALL RADIANS LISTED FOR SPHERES LARGER THAN 60' DIA WHEN CALCULATING "S"

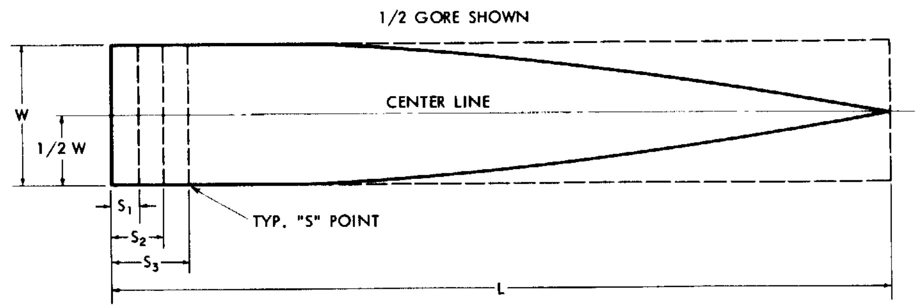
* SHRINKAGE CORRECTION FACTOR IN GORE TO OBTAIN MORE SPHERICITY AFTER FABRICATION

$S = * \times R \times Q$ CONSTANT = 67.5'

$1/2\,W = \frac{\pi R \cos Q}{N}$ CONSTANT = 24.006"

PATTERN TOLERANCE

± 1/64 - 1/2 W
± 1/4 - OVERALL LENGTH (46N TO 46S)
± 1/8 - ℄ VARIANCE FROM THEORETICAL STRAIGHT LINE BETWEEN STATIONS 46N TO 46S



	Q RADIANS	COS. Q	S		1/2 W
0°	0.0000	1.00000	1	0.000'	24.006"
2°	0.0349	0.99939	2	2.355' (4.260)"	23.991"
4°	0.0698	0.99756	3	4.711' (8.532)"	23.947"
6°	0.1047	0.99452	4	7.067' (0.804)"	23.874"
8°	0.1396	0.99027	5	9.423' (5.076)"	23.772"
10°	0.1745	0.98481	6	11.778' (9.336)"	23.641"
12°	0.2094	0.97815	7	14.134' (1.608)"	23.481"
14°	0.2443	0.97029	8	16.490' (5.880)"	23.292"
16°	0.2793	0.96126	9	18.852' (10.224)"	23.076"
18°	0.3142	0.95106	10	21.208' (2.496)"	22.831"
20°	0.3490	0.93969	11	23.557' (6.684)"	22.558"
22°	0.3840	0.92718	12	25.920' (11.040)"	22.257"
24°	0.4189	0.91354	13	28,275' (3.300)"	21.930"
26°	0.4538	0.89879	14	30.631' (7.572)"	21.576"
28°	0.4887	0.88295	15	32.987' (11.844)"	21.196"
30°	0.5236	0.86603	16	35.343' (4.116)"	20.789"
32°	0.5585	0.84805	17	37.698' (8.376)"	20.358"
34°	0.5934	0.82904	18	40.054' (0.648)"	19.901"
36°	0.6283	0.80902	19	42.410' (4.920)"	19.421"
38°	0.6632	0.78801	20	44.766' (9.192)"	18.916"
40°	0.6981	0.76604	21	47.121' (1.452)"	18.389"
42°	0.7330	0.74314	22	49.477' (5.724)"	17.839"
44°	0.7679	0.71934	23	51.833' (9.996)"	17.268"

	Q RADIANS	COS. Q	S		1/2 W
46°	0.8029	0.69466	24	54.195' (2.340)"	16.676"
48°	0.8378	0.66913	25	56.551' (6.612)"	16.063"
50°	0.8726	0.64279	26	58.900' (10.800)"	15.430"
52°	0.9076	0.61566	27	61.263' (3.156)"	14.779"
54°	0.9425	0.58778	28	63.618' (7.416)"	14.110"
56°	0.9774	0.55919	29	65.974' (11.688)"	13.423"
58°	1.0123	0.52992	30	68.330' (3.960)"	12.721"
60°	1.0472	0.50000	31	70.686' (8.232)"	12.003"
62°	1.0821	0.46947	32	73.041' (0.492)"	11.270"
64°	1.1170	0.43837	33	75.397' (4.764)"	10.523"
66°	1.1519	0.40674	34	77.753' (9.036)"	9.764"
68°	1.1868	0.37461	35	80.109' (1.308)"	8.992"
70°	1.2217	0.34202	36	82.464' (5.568)"	8.210"
72°	1.2566	0.30902	37	84.820' (9.840)"	7.418"
74°	1.2915	0.27564	38	87.176' (2.112)"	6.617"
76°	1.3265	0.24192	39	89.538' (6.456)"	5.807"
78°	1.3614	0.20791	40	91.894' (10.728)"	4.991"
80°	1.3962	0.17365	41	94.243' (2.916)"	4.168"
82°	1.4312	0.13917	42	96.606' (7.272)"	3.340"
84°	1.4661	0.10453	43	98.961' (11.532)"	2.509"
86°	1.5010	0.06976	44	101.317' (3.804)"	1.674"
88°	1.5359	0.03490	45	103.673' (8.076)"	0.837
90°	1.5708	0.00000	46	106.029' (0.348)"	0.000

Figure 3-21. Gore Configuration

increment marking system, (10) minimum loss of gores due to cutting error, and (11) cutting of many castoff gores which could not have been cut by the former method.

3.5 BEACON REINFORCEMENTS

The rapid acceleration of the sphere surface observed in suborbital test AVT 1, in which speeds approached 40 feet per second, indicated that the attachment of beacons, which weighed 6 pounds with the attendant solar modules, would require specially reinforced areas.

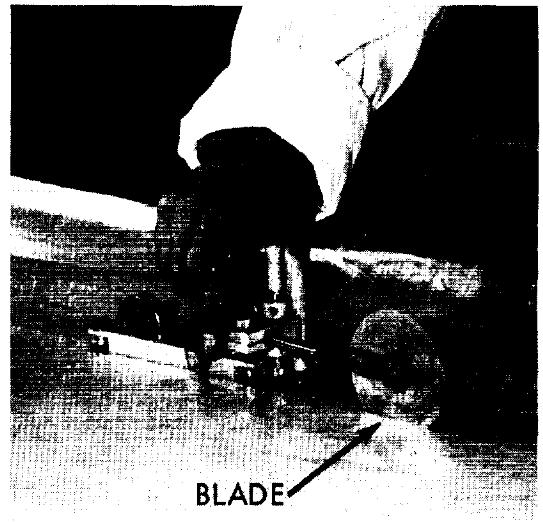


Figure 3-22. Gore Cutter

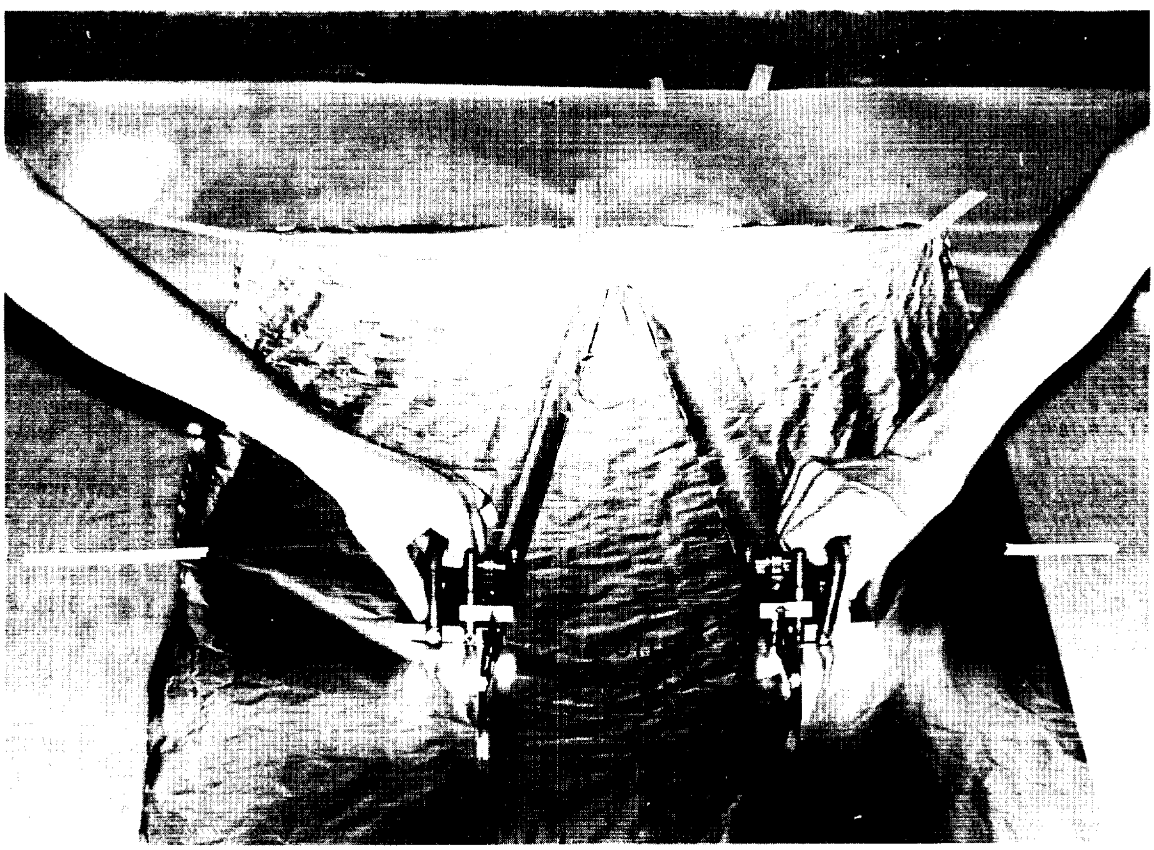
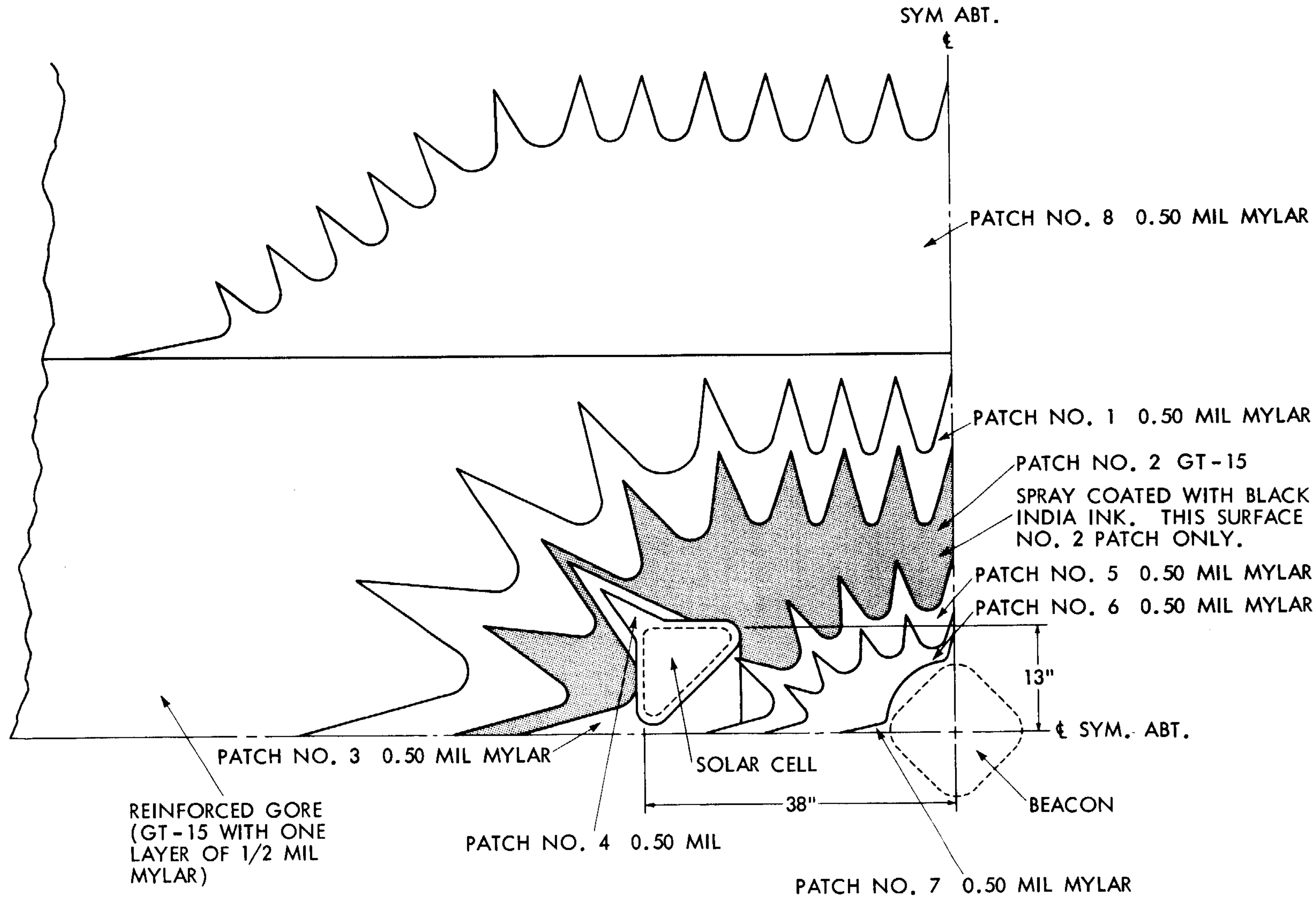


Figure 3-23. Gore Cutters in Operation



NOTE: THIS IS A ONE QUARTER VIEW.

Figure 3-24. Beacon Area Reinforcements

Tests	Results
Thermal shock	25 cycles no delamination, 50 cycles slight delamination at edges (GT-301 begins to fail at 40 cycles)
Tensile	Shear equal to GT-301, Peel 15% greater strength than GT-301
Vacuum out-gassing	0.08% in 4 hrs. at 10^{-3} mm Hg compared to 0.5% for GT-301
Shrinkage	0.07% more than GT-301 at 110°C for 3 days
Creep	No creep detected, 4 lb per inch tension for 48 hours 110°C (equal to GT-301)

The use of A-40 adhesive required different techniques than had previously been used with GT-301. First, the A-40 adhesive does not dry hard as does the GT-301 when applied to the material to be sealed. Therefore, the A-40 was applied to both surfaces to be joined and allowed to dry until tacky before joining, whereas the GT-301 was applied to one surface only.

The tacky surfaces then presented a second need for procedure change. The thin gauge Mylar tended to wrinkle when handled allowing the adhesive coated surfaces to stick together. Separation of the material was not possible without destroying the patch. The problem was overcome by applying a removable paper backing to the Mylar before coating with adhesive. The paper provided the necessary stiffness during handling and was easily removed after the patch was bonded to the sphere surface.

A third change in technique resulted from air bubbles which became entrapped between the material during joining. To relieve this situation, pinholes on 1/2-inch centers were made in the Mylar before bonding. This provided escape vents for the entrapped air. To determine the degrading effect of the pinholes on the Mylar strength, drop tests were conducted which showed no correlation between failure points and pin holes.

The improved method for attaching the beacon reinforcement was demonstrated in the static inflation test of sphere 16 in December 1963, at Lakehurst, New Jersey. The sphere surface in the beacon area was essentially free of distortion due to the reinforcements.

3.6 GORE SEALING

3.6.1 INITIAL TECHNIQUE

Gores for sphere 1 were sealed with the same sealer used on the Echo I satellites. Satisfactory seams were produced, but a serious drawback of the sealing method soon became apparent since the gores had to be handled excessively as they were being sealed. The excessive handling caused many accidental tears, and added wrinkles which made the following operation, pleat folding, more difficult.

Therefore, before commencing with sealing unit 2, the sealer and table were redesigned. The traveling sealer (Figures 3-25 and 3-26) included a gore dispenser (parallel to and directly above sealing table) which moved so that the edge of the gore dispensed was always close to the edge of the previously sealed gore. This feature minimized handling as the gores were sealed together. The sealer also included a rotating belt sealing rail whose movements were coordinated with the motion of the sealer, so that no excess motion of the gores (in relation to table and each other) was required as they were sealed together. The sealing and folding table was modified by contouring the sealer side of the table to conform to the gore contour. The sealing machine and operators travelled along the curved table to simultaneously dispense and join new gores to the previously sealed gores. This permitted simultaneous sealing and pleat-folding operations. Spheres 2 through 15 were fabricated with this equipment and technique.

The splice plate tape consisted of GT-15 laminate, coated with 0.5 ±0.2 mil of GT-301 adhesive slit 1 inch wide. Shelf life of the tape under refrigeration is in excess of 6 weeks; therefore, to ensure optimum bonding qualities, use of the sealing tape was limited to 31 days after date of manufacture. In-process records of tape manufacture referencing laminate roll material and adhesive lot numbers were all referenced to sealing records for each individual seal in each sphere and were kept on file with the seal inspection records for the units.

Basic sealing tolerances and requirements allowed 0.02 inch maximum overlap and 0.04 inch maximum gap of the gores at the butt joint. The sealing tape bonded the gores together in a butt type joint with the tape applied on the outside surface of the laminate gore material. A minimum of 3/8 inch of tape in contact with each gore at any point along the butt joint of the seam length was also required. Sample lengths of seal were run before and after each full length sphere seal. These samples were tested for strength and resistance to detonization.

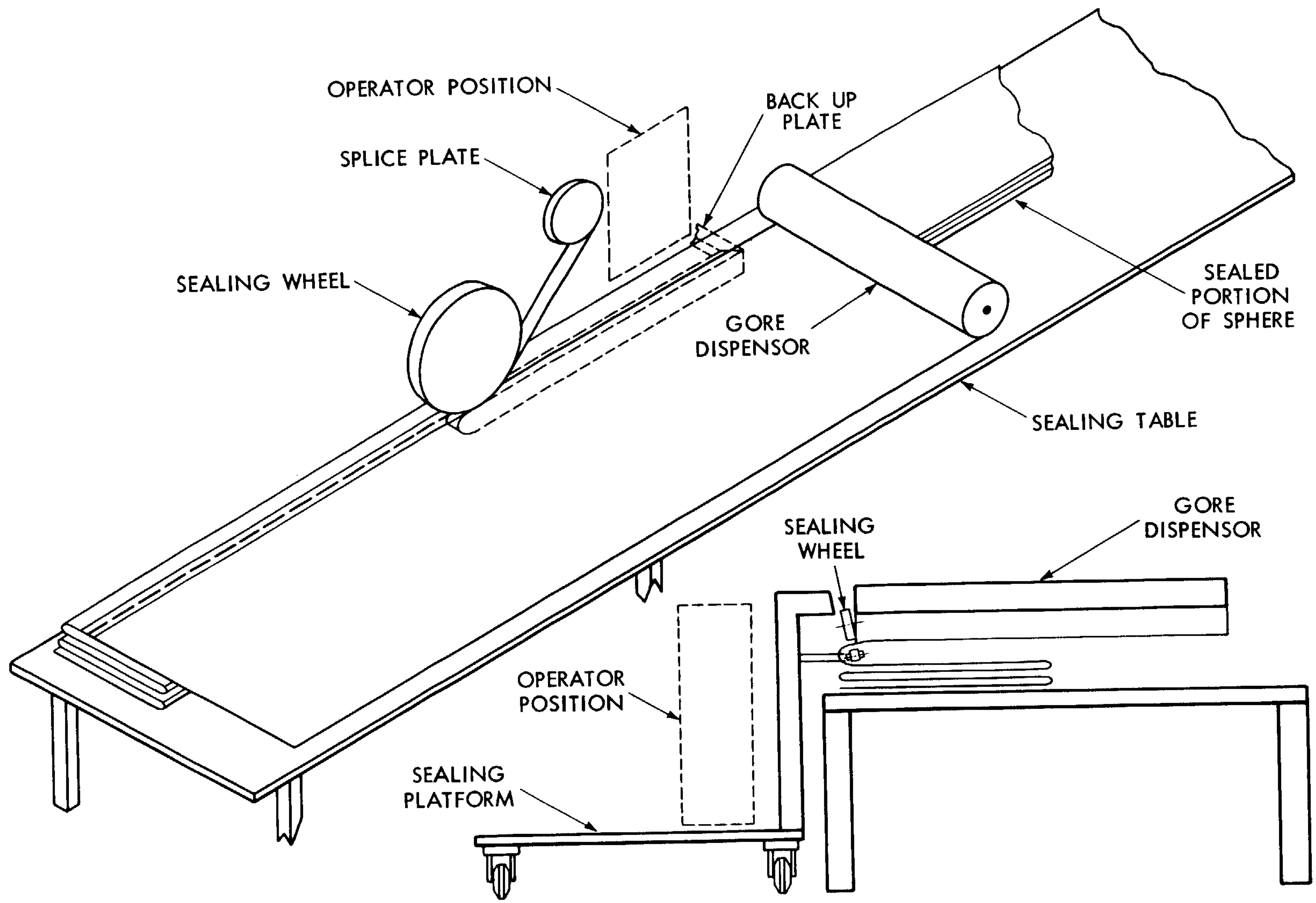


Figure 3-25. Diagram of Traveling Belt Sealer

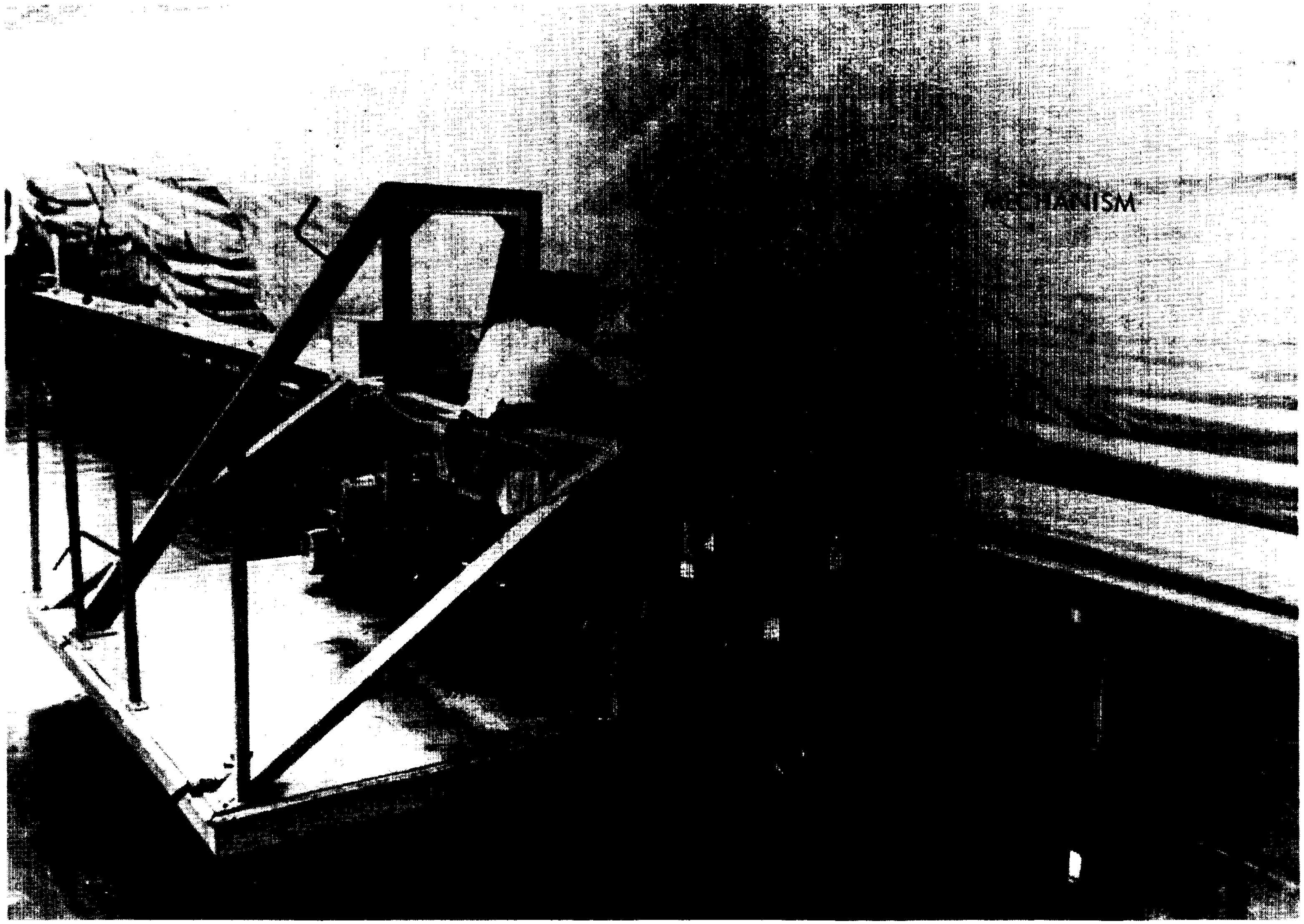


Figure 3-26. Traveling Belt Sealer

Spheres 7 through 15 had two sets of two X-91 gores at 180 degrees to each other. These gores were sealed with the standard X-15 (301) tape on the exterior of the butt joint, and had an additional tape full-length on the interior. The interior tape was made of 50 gauge (0.5 mil) Mylar, 3/4 inch wide coated with 00.5 ±0.2 mil GT-301 adhesive. The adjoining edges of the beacon reinforcement patch to the instrumentation gores were also sealed in this manner.

3.6.2 SEALING IMPROVEMENTS

Observations of spheres 9, 11, and 13 during static inflation tests at Lakehurst, New Jersey, in June and July of 1963, indicated irregular areas along the seams (Figure 3-27), which were traced to sealing methods. Sealing the large Echo II spheres required methods which minimized or eliminated chances for human error because of the 22,500 feet of faultless seal required and the inability to test it. Conditions such as seal shrinkage and material castoff which are difficult to detect during sealing can be seen clearly on an inflated sphere. The inflation tests emphasized the need for modifying fabrication techniques to compensate for long seals, many gores, and material imperfections. In an effort to improve sealing techniques, an investigation was conducted under the Quality Improvement Program (NAS 5 3243, Mod 8) aimed at obtaining gas-tight, strong, smooth uniform seams and seam areas.

The approach taken to improve seal smoothness was to spread small irregularities out over the full length of the gore. This was accomplished by using a sealing rail equal in length to the gore (as shown in Figure 3-28). The curvature of the rail was slightly more than the gore edge to allow the lower gore edges to hang tension free. The long rail permitted layup, alignment, and inspection of the butt joint before it was sealed. In actual operation these steps were done simultaneously for efficiency. Sealing was accomplished with a self-propelled, self-guiding sealer which ran along the sealing rail (Figure 3-29).

The curved rail sealer provided uniform gore alignment by permitting the operators to match the gore to the rail which served as a reference standard. The butt joint was easy to correct if out of tolerance since ample time was available before the seal was made. Better inspection was possible because time and space were available for inspectors to observe the butt joint before the sealing operation.

Handling procedures and protective devices were developed to protect the material from being wrinkled by workers and inspectors. New gores were dispensed by the sealing machine as it travelled empty on the return cycle. A layup crew stuck the gore to the rail in unison; thus, the new gore was positioned in a minimum time with little handling. The sealed portion of the sphere was aligned

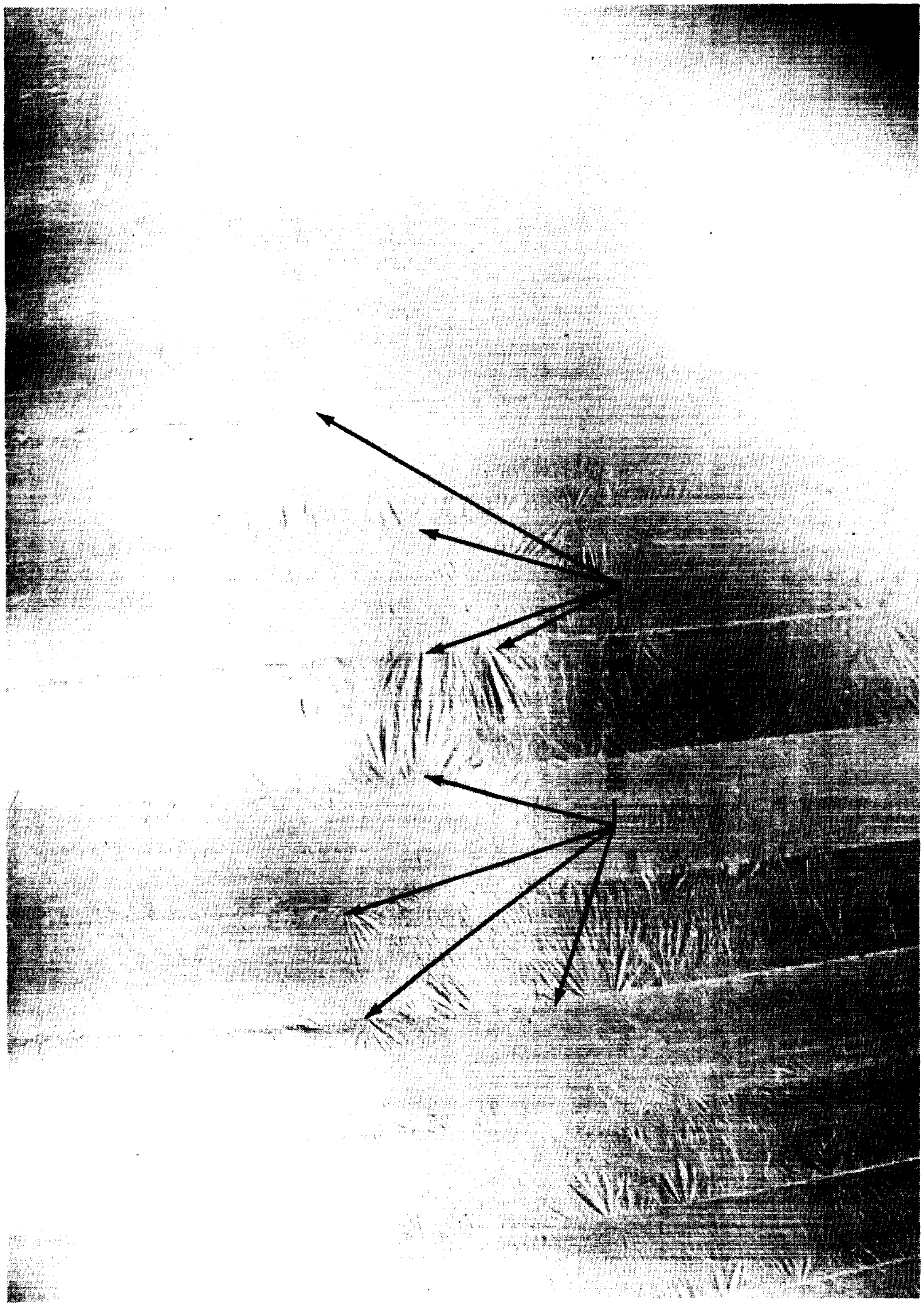


Figure 3-27. Seam Irregularities

Figure 3-28. Seaming Rail

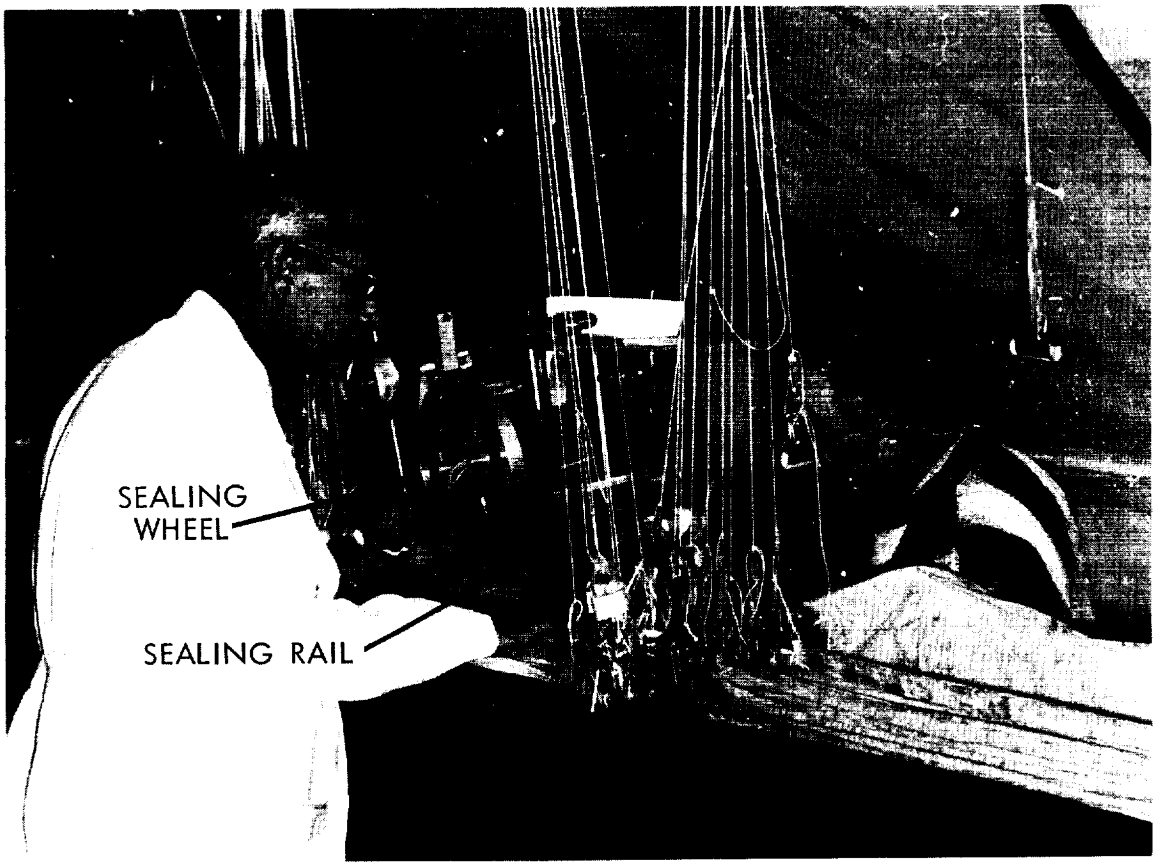


Figure 3-29. Sealing Operation

during sealing operation to facilitate alignment and removal of the new gore from the rail. After gores had been joined they were suspended along the opposite side of the rail by clips fastened to overhead bars ready for additional gores to be sealed on. As more gores were added the clips were rolled back to provide more room for new gores. The suspension and sealing operation continued until one half of the sphere was completed. This half sphere was then set aside until the second half was fabricated. The two halves were then joined together using the traveling belt sealer which was also used on the final seal.

A number of studies leading to the overall improved method for sealing are discussed in detail below.

3.6.2.1 Gore Alignment

The butt joint tolerance (+0.040 gap, -0.020 overlap) required the gore edges to be accurately positioned and securely held during application of the seal tape. This was accomplished by laying the gore edges on a tacky sealing rail. The tacky surface prevented gore movement and shrinkage during tape application. The use of liquid tack adhesive led to leaving traces of adhesive in the sphere even after careful cleaning of the back of each seal with solvent. Replacement of the tack adhesive was sought to eliminate the blocking possibility in the sphere. The methods considered were a rubber sealing rail with small vacuum holes to hold the gore edge or a porous vacuum sealing rail (as shown in Figure 3-30) to hold the gore edges.

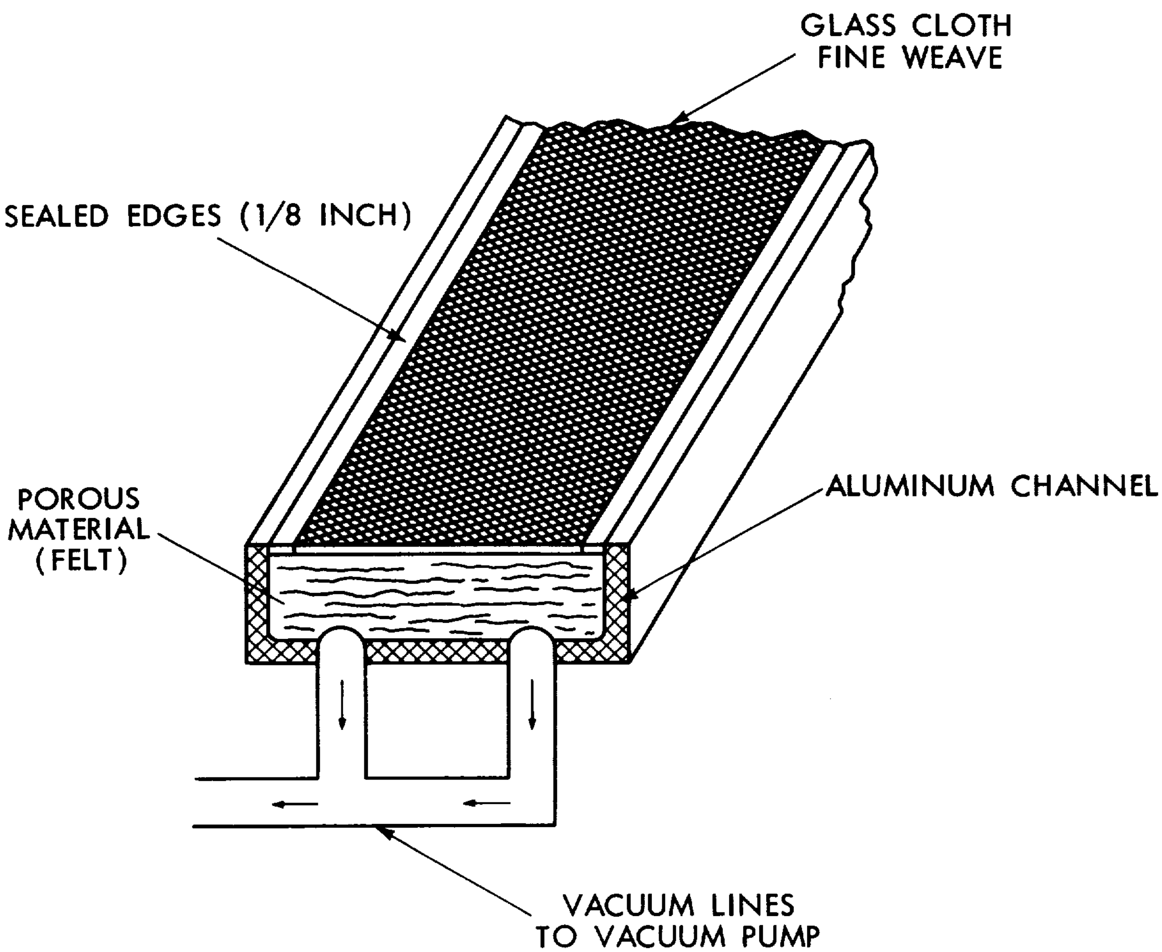


Figure 3-30. Vacuum Sealing Rail

Vacuum holddown was investigated since it provided a different method of gore-to-rail attraction which would not later cause blocking. The rubber rail did not have sufficient holding force unless the holes were 1/8 inch in diameter. Unfortunately, holes of this size left bubbles under the seams which were undesirable for space use. The vacuum porous materials tried were found to be so soft that many wrinkles appeared along the seal edges.

A tacky silicone-base pressure-sensitive tape (3M Y 6904) attached to a rubber covered rigid rail (Figure 3-31), a method which had been used with success with higher tensile materials, was tested and shown to be effective. The adhesive was not affected by heat and could be used over 50 times without significant loss of tackiness. However, removal of the seal from the tacky rail caused excessive yielding of the fragile foil-Mylar laminate. Chalk powder applied to the tape in proper amounts satisfactorily reduced the tack to operable levels, but was considered unreliable for large areas because of uniformity problems. A controllable method of reducing the tack strength was to cover the tack with a thin perforated film. The small holes permitted the gore edges to be securely fastened yet easily removed since the effective bond area was much smaller. Tack control was regulated by the perforation hole size and spacing. Holes 1/4 inch in diameter and 1/2 inch center to center proved to be optimum.

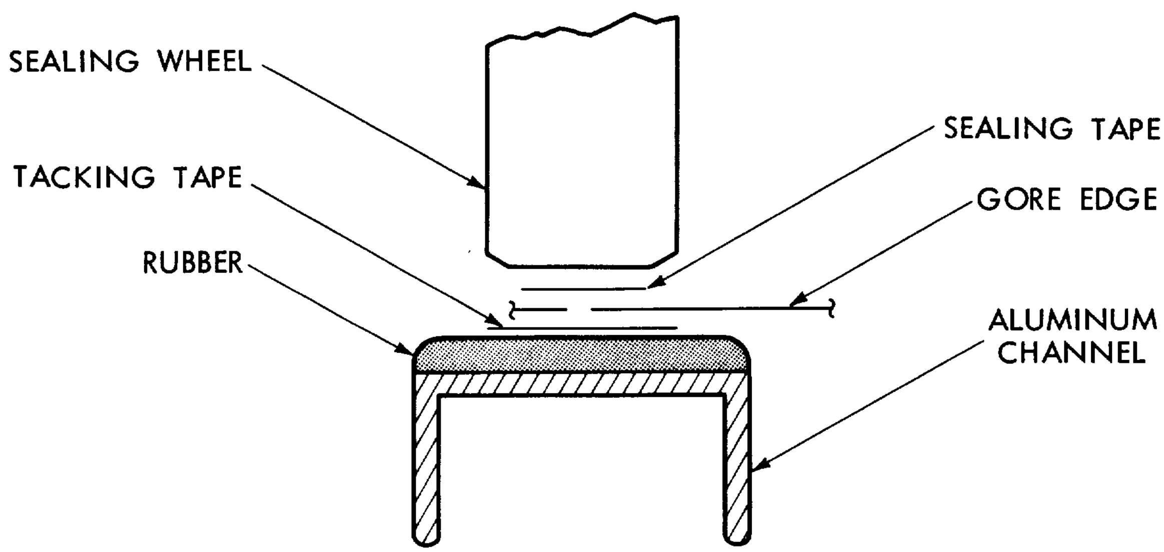


Figure 3-31. Rigid Sealing Rail

A number of perforated tapes were investigated for tack control. These included polyethylene, Mylar, polypropylene, biaxially oriented polypropylene, as well as some Teflons and vinyls. The Mylar material was most satisfactory except that the GT-301 adhesive from the tape being sealed was forced between the gore edges and adherred to the Mylar. Thus, on seal 87 in sphere 16, production was interrupted until an improved tape could be tested for use. Improved results were obtained with biaxially oriented polypropylene which had not been Corona treated for adhesion of inks or adhesives. Perforated tape was made from this material throughout the remainder of the program.

3.6.2.2 Match Mark Alignment

Match mark alignment methods were studied, since the inflated spheres had large "crow foot" marks which indicated alignment difficulties. Alignment marks were pierced along the edges of the gores about every 2.5 feet. When two gores were joined during sealing they were aligned to ±1/8 inch. This tolerance was sometimes difficult to meet at some stations because differences in gore edge lengths were caused by material castoff. Proper alignment of a misplaced mark would cause "crow foot" wrinkles as the operators attempted to stay within tolerances. The "crow foot" wrinkle problem was finally solved by disregarding occasional mismatch of marks and placing emphasis on average smooth alignment of marks over the gore length to achieve a smooth wrinkle free layup on the sealing rail.

3.6.2.3 Edge Deformation

Deformation along the gore edges was noted on some seals made on the traveling belt sealer. With changes made in the sealing system, the solution to this problem was simplified. A rubber covered metal rail as shown in Figure 3-31 had been substituted for the flexible belt sealer. The covering was 3/16 inch thick 60 durometer neoprene rubber. The sealing wheel as shown in Figure 3-32 had 5 degree relief and 1/32-inch radius at the edge. Sample seals made on the improved equipment showed no sign of edge deformation along the seals.

In the initial use of the new rail sealer and traveling sealer wheel in the first 36 seals for sphere 16, a sharp deformation at the edge of the wheel was observed. This occurred only in locations where the wheel had strayed from its path on the tape and thus had exposed one edge of a single thickness of GT-15 material to the pressure between the sharp edge of the wheel (1/64-inch radius) and the resilient backing material. This lead to a defect which occurred at about five places in these seals which on diaphragm testing showed strengths of only 50 to 80 percent of the strength of the parent material. Correction was made by inspecting and repairing the seals 3 through 36 using a pressure-sensitive Mylar tape and by revising the surface contour of the wheel. The accuracy of inspection for repair of the defect and the effectiveness of the repair on these seals made before the sealing of any orbital material was borne out by the high test pressure (23,000 psi skin stress) achieved in the static inflation test.

3.6.2.4 Sealing Temperature

A study of heat sealable adhesives was conducted to find ways of lowering the 380° F sealing temperature requirement in an attempt to reduce seal shrinkage. Two lots of heat sealable tapes were made with GT-15 material and 1/2-mil coatings of GT-301 and A-40 adhesive. The tapes were cut to 1-inch width and placed in cold storage for 15 days before using to simulate typical usage conditions. Sample seals were prepared which covered a sealing temperature range from 250 to 380° F. They were then cured for 7 days before tensile, peel, and thermal shock tests were performed. The test data shown in Table 3-9 indicate that the seal strength improved as the sealing temperature was reduced. It appears that the highest values were from seals made between 250 and 325° F. Based on these tests it was decided to take samples from practice gores sealed on the new sealing equipment for confirmation which were sealed at 270 to 320° F. These tests yielded similar results, except that some sporadic bond separations were detected at the 270° F.

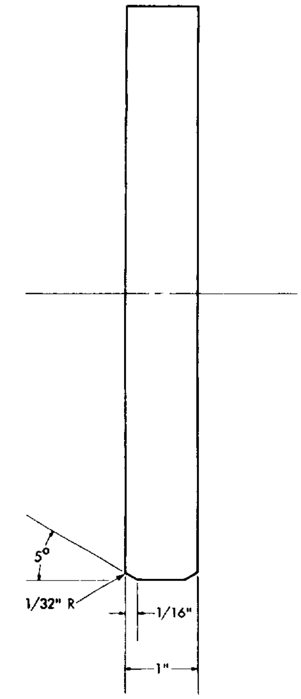


Figure 3-32. Sealing Wheel Edge Details

In the final analysis it was concluded that shrinkage could be minimized by operating at 300° F at 6 feet per minute and that fully reliable seals would result. Although good bonds could be made at lower temperatures and higher speeds, reliability had to be considered the more important. The A-40 adhesive tests results appeared attractive, but were not considered because of satisfactory performance with GT-301 adhesive with its established reliability.

3.6.2.5 Seal Shrinkage

Two seal shrinkage tests were performed to determine the shrinkage that takes place in a 212-foot long seal. The first test used a 212-foot long strip of material and equivalent length tape. The seal was run at 380° F and then remeasured. It was found that the material remained almost the same length but the tape had shrunk 4 inches thus using 212 feet, 4 inches of tape.

Seal shrinkage tests were performed with the curved rail and traveling sealing wheel system to determine the extent of shrinkage in the sealing process. The results indicated that the shrinkage was approximately 4-3/4 inches in 212 feet (0.18 percent) when a temperature of 380° F previously used for Echo sealing was employed. When the temperature of the wheel sealer was reduced to 300° F and with the sealing rate of 4-1/2 feet per minute the seal shrinkage was about 2-3/4 inches (0.11 percent). The method used for the study of seal shrinkage consisted of carrying out a seal on two gore edges which had been laid up on the rail and after completion of the seal removing the material from the rail, cutting

Table 3-9
GT-301 and A-40 Seal Test Results

Sample No.	Adhesive	Temp. Sealed (°F)	Room Temp. Tensile (lb/in)	150°F* Tensile (lb/in)	180°F Peel	Thermal Shock
1	GT-301	375	11.5	9.5	1.0	OK
2	GT-301	375	11.0	9.0	0.9	OK
3	GT-301	350	12.0	9.5	1.1	OK
4	GT-301	350	12.0	9.0	1.4	OK
5	GT-301	325	11.5	9.0	1.4	OK
6	GT-301	325	11.5	8.5	1.4	OK
7	GT-301	300	11.5	9.1	1.5	OK
8	GT-301	300	12.0	8.5	1.7	OK
9	GT-301	275	11.5	9.0	1.4	OK
10	GT-301	275	12.0	9.0	1.0	OK
11	GT-301	250	12.0	10.0	1.5	OK
12	GT-301	250	12.0	9.0	1.6	OK
13	A-40	300	11.5	9.0	1.1	OK
14	A-40	300	12.0	9.0	1.5	OK
15	A-40	275	11.5	9.0	1.6	OK
16	A-40	275	11.5	9.0	1.6	OK
17	A-40	250	12.0	9.5	1.8	OK
18	A-40	250	12.0	9.5	2.0	OK
19	A-40	225	12.0	9.5	1.2	OK
20	A-40	225	12.0	9.0	2.0	OK
21	A-40	200	12.0	9.5	0.7	Failed
22	A-40	200	12.0	9.0	0.9	Failed

*No bond failures occured in 150°F tensile tests and no indication of adhesive creep was noted.

the gore away from the tape, replacing the tape on the rail, and measuring its length with respect to the original match marks. The original lengths of the tapes were not measured in these experiments.

These observations are particularly important when it is considered that the difference between the length of the curved rail and the straight line from one end of it to the other is only about 3/8 of an inch. The seal shrinkage, therefore, shortens the edge of each gore as it is sealed to an extent great enough to preclude the complete attachment of the second edge of a sealed gore to the curved rail. To preserve the advantages of the curved rail sealing method, it was therefore necessary to devise techniques whereby the sealed sphere portion of the east edge of the gore last sealed into the sphere could be placed on the sealing rail. This operation started at the south end of the rail and approximately 30 percent of the gore was aligned. In the meantime the entire west edge of the new gore was applied to the rail and its conformity with match marks established. Sealing was then started and as the sealing operation was completed the south end of the gore seal was removed from the rail to permit attachment of the sphere gore ahead of the sealing wheel. By this method of operation it was possible to achieve the advantages of the curved rail sealer, which lay primarily in improved accuracy in alignment, without complete redesign of the equipment at this stage.

Seal tests were continued; the results of the tests are tabulated in Table 3-10. Echo II material was used throughout, but the material was subjected to different treatments. The first 15 sets of results represent material that had been heat treated for 72 hours at 110°C; the second set of results represent material that had not been heat treated. All materials were Alodine and ink coated. A sealing speed of 4 feet per minute was selected as most representative of past work and of work to be done in the foreseeable future.

Several 12.5-foot diameter spheres fabricated with the new method were compared to spheres built on the belt sealer. Close inspection of the seal areas at low skin stress (below 3000 psi) revealed an improved spherical smoothness. The spheres built on the belt sealer exhibited alternating puckers along the seals. Puckers and stretch marks were absent from the seals of the spheres fabricated on the curved rail. Alignment of match marks was within tolerance, but total gore alignment became less dependent on an individual pair of marks since several sets of marks could be aligned at the same time. The end result was an elimination of alternating stretch marks along the seals. An additional benefit noted was that any gores which contained castoff could be detected before sealing had started. Detection was possible since each gore was laid on a marked rail. Gores which did not fit this standard were rejected before the sealing operation started.

Table 3-10
Seal Shrinkage Tests with GT-15-1

Sample Number (1)	Sealing Temp (°F)	Seal Load lb/in width	Shrinkage Measurements (%)		Average Percent Shrinkage (4)	
			Half (2)	Half (3)		
1	275	60	0.022	0.032	0.108	
2	275	60	0.028	0.030	0.116	0.17
3	275	60	0.062	0.082	0.288	
4	300	60	0.032	0.070	0.204	
5	300	60	0.000	0.045	0.090	0.13
6	300	60	0.020	0.022	0.084	
7	325	60	0.048	0.043	0.182	
8	325	60	0.042	0.064	0.212	0.20
9	325	60	0.040	0.062	0.204	
10	350	60	0.026	0.036	0.124	
11	350	60	0.028	0.046	0.148	0.14
12	350	60	0.048	0.026	0.148	
13	375	60	0.034	0.040	0.148	
14	375	60	0.032	0.038	0.140	0.15
15	375	60	0.055	0.029	0.168	
16	275	60	0.008	0.016	0.048	
17	275	60	0.066	0.032	0.196	0.12
18	300	60	0.004	0.012	0.032	
19	300	60	0.020	0.006	0.052	0.05
20	300	60	0.022	0.012	0.068	
21	325	60	0.015	0.028	0.086	
22	325	60	0.014	0.016	0.060	0.06
23	325	60	0.008	0.008	0.032	
24	350	60	0.060	0.048	0.216	
25	350	60	0.022	0.012	0.068	0.11
26	350	60	0.010	0.016	0.052	
27	375	60	0.022	0.024	0.092	
28	375	60	0.032	0.020	0.104	0.09
29	375	60	0.022	0.020	0.084	

NOTES:
1. Test numbers 1-15: GT-15-1 Alodine coated, ink coated, and heat treated for 72 hours at 110°C. Test numbers 16-29: GT-15-1 Alodine and ink coated.
2. GT-15-1 is GT-15 laminate, laminated at 300 ±10°F with Mylar coated both passes.
3. Backing tape for seals: paper coated with 9 oz/yd^2 latex-base pressure-sensitive adhesive
4. 25 inch gauge length for measurements
5. All seals performed at 4 feet per minute
6. 50-60 Durometer rubber for seal backup for all tests

Spheres 16, 17, and 18 were fabricated by the new curved rail sealing method. The improvements resulting from the Quality Improvement Program were successfully demonstrated in the static inflation test of sphere 16 in December 1963 at Lakehurst, New Jersey.

3.7 PLEAT FOLDING

The first stage of sphere packing is pleating, i.e., folding the gores longitudinally in a tapered configuration so that the accordion folding operation (discussed later) could be performed. The pleating was accomplished by the use of templates (Figure 3-33) fabricated from 10 mil Mylar extending to about 20 feet from the ends of the sphere. The ends were not folded until sealing was completed. The templates were contoured on one edge, straight on the other, and were calculated to pleat 3.4 folds per gore with the widest section at the equator being 13-1/2 inches. After pleating was completed, the stack was divided with the straight edges of the pleats in the center of the stack and the contoured edges facing out (Figure 3-34).

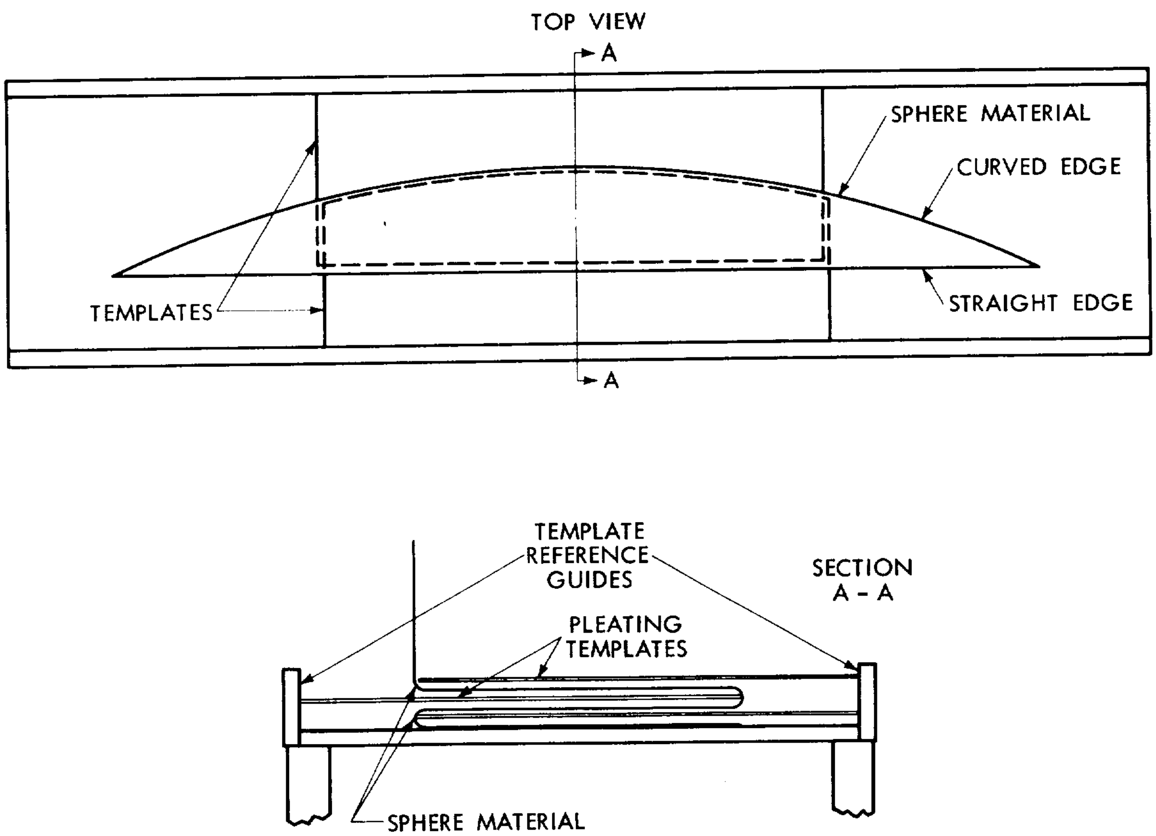


Figure 3-33. Pleating Operation Setup

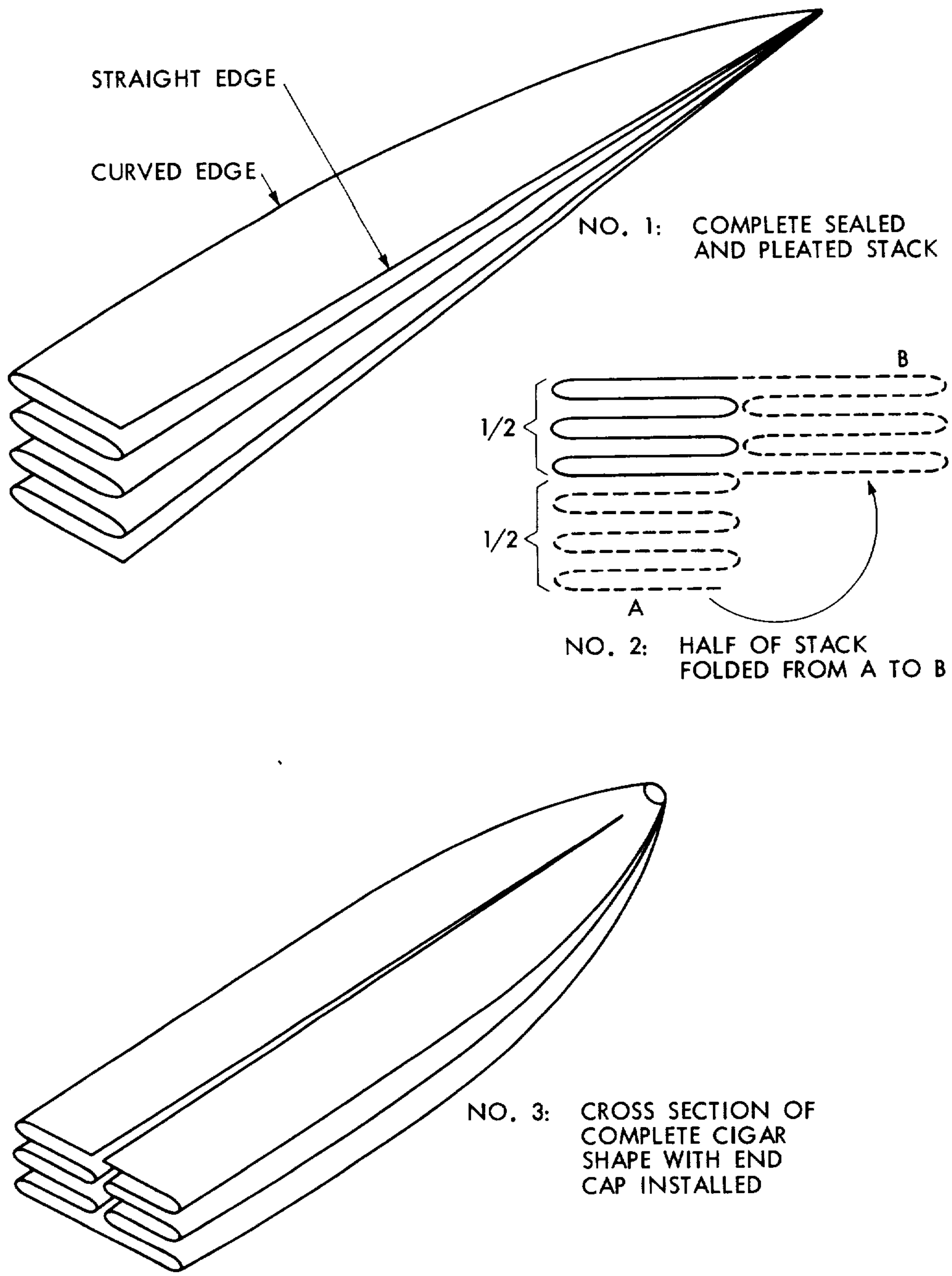


Figure 3-34. Pleating Operation

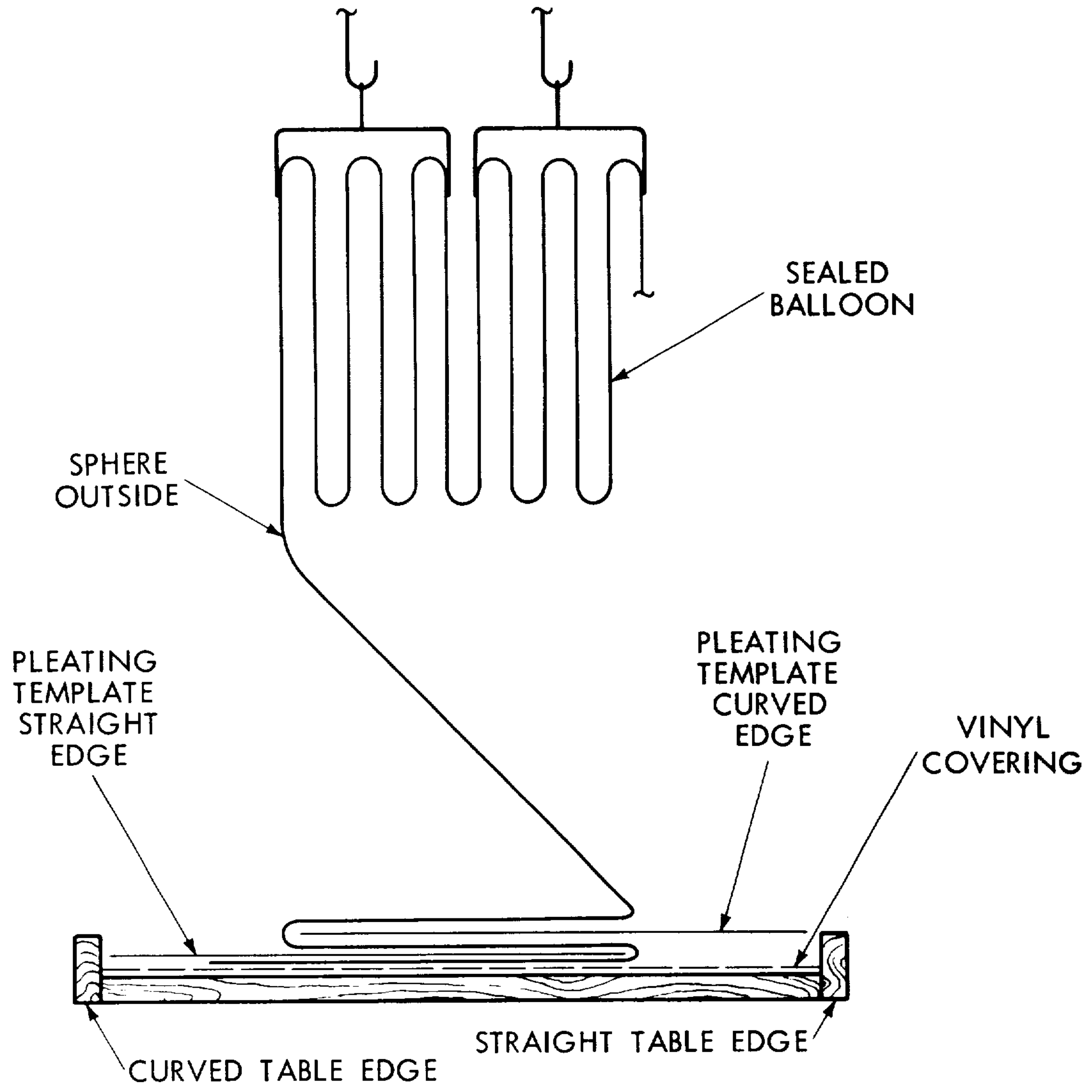
3.7.1 ORIGINAL METHOD

The pleating operation for spheres 1 through 15 (except for static inflation test) was performed during the sealing operation, about one gore behind the sealer. The first gore was manually dispensed from its core onto the table and then folded on its center line using a straight edge template. Curved templates conforming to the gore edge were used for holding the sealed contour in place while making the center line fold. After the second seal was completed on the edge of the second gore, the second gore was semifolded by the machine and was ready for the template folding. The curved template was then placed to fold and retain the shape of the sealed edge as the straight edge template was inserted between the previous seal and the unsealed edge of the gore. The straight template was then applied to the stops or the curved edge of the table to determine the centerline fold location. The two templates were left in place as the next gore was sealed and then pleated with additional templates. The first set of templates was then carefully removed and the procedure repeated for the remainder of the sphere.

3.7.2 PROCESS IMPROVEMENT

The packing operations performed with the full-scale test spheres indicated a need for easier and more efficient pleating methods. As a result of improvements in the sealing technique using the rail guided contour sealer, modifications to the pleating operation were required. The basic pleating techniques described previously were maintained except that they were not employed until all the gores had been sealed together. This required suspension of the sphere above the pleating table (Figure 3-35) and lowering one gore at a time for pleating until the complete sphere had been pleated.

Experience also indicated that a lower stack height could be achieved if the number of pleats was kept to a minimum in the sphere ends or polar tips. The center or equator of the sphere required about 3.4 pleats per gore to meet the maximum usable width dimension (28.6 inches) of the packing container. However, an equal number of pleats per gore was difficult to achieve near the polar caps since they tapered to a point. A low profile stack was achieved by modifying the pleating pattern near the poles. By widening the polar pleats the thickness of the poles was reduced to a fraction of the original. Widening of the poles eliminated many narrow pleats and bulky creases, thereby reducing the stack height. The frequency and location of dropping pleats was difficult to predetermine, but was achieved by experience during pleating. Pleats were dropped when the wide pattern consumed the available material, and were resumed as more material became available on subsequent pleats. In addition, the reduced number of creases permitted by the drop pleating greatly reduced aluminum fatigue in the polar region.



CROSS SECTION VIEW

Figure 3-35. Improved Pleating Method

The orbital and backup spheres were pleat-folded from pole to pole to approximately 3.4 pleats per gore width, except for the last 30 feet at each pole. Drop-folding on the last 30 feet near each pole gave a uniform stack width close to 6 inches. The maximum width of the pleated spheres at the equator was 28 inches.

3.8 AIR EVACUATION HOLES

Holes were made in the spheres to permit evacuation of entrapped residual air from inside the inflatable spheres prior to closing the canister in the evacuated chamber. Except for the static inflation units, the holes were punched after 3/4-inch diameter GT-15 (301) tape reinforcement tabs were sealed in place. The locations were on a centerline 1 inch from the seal on each set of instrumentation gores and were spaced to index the fold length, on fold numbers 1 through 40 (Figure 3-36). This location coincided with the centerline of the stack formed by pleat-folding the sphere. The 160 holes located as described were 1/16-inch diameter. One reinforced hole 1/8-inch in diameter was located in the center of each polar cap.

The holes were made upon completion of 105 seals, either before or after pole cap installation, but before insertion of subliming material. The curved sealing rail permitted making the holes after sealing each of the two sets of reinforced instrumentation gores while still located on the sealing rail. This method considerably reduced handling of the material.

3.9 ELECTRICAL CONTINUITY JUMPER STRIP

A jumper strip was installed on each sphere around a circumference 2 inches from the edge of each pole cap (Figure 3-37) using a Gulton ultrasonic sealer, electronically and pneumatically operated. The purpose of the jumper strips was to ensure dc continuity on the surface of the sphere. The possibility of contact between gores at the butt joints was possible but not considered likely.

The jumper strips were non-Alodine coated GT-15 material, one-half inch wide and 172 inches full continuous length. The Alodine coating was removed from an area approximately one-quarter square inch on each gore where the ultrasonic weld was made. A continuity check was made on each unit with an ohmeter. The jumper strip and gores were vented near each weld to prevent air entrapment. The continuity jumper strips were covered with a 1-inch wide seal of GT-15 (301) tape to prevent gas leakage of damage to the jumper strip.

3.10 POLE CAPS

The polar caps for the spheres were fabricated from GT-16 laminate (0.18 mil aluminum foil bonded to both sides of 1 mil Mylar) which had been Alodine coated to 184 ± 3 mg/ft and manually ink-coated with Higgins No. 44 black waterproof ink on the inside. The caps were cut to 52 inches diameter and attached to the sphere with GT-301 heat sealable adhesive on a 1-inch wide circumferential ring (Figure 3-37).

A rubber covered mandrel, 72 inches in diameter, supported the end section of the spheres for the end cap installation. The center point for marking the 50-inch diameter cutout was located by triangulation from the end increment alignment marks. The concentric circles for extremities of polar cap and continuity strip location were marked from the same center point. Precise location of the end caps was essential for accurate spherical shape.

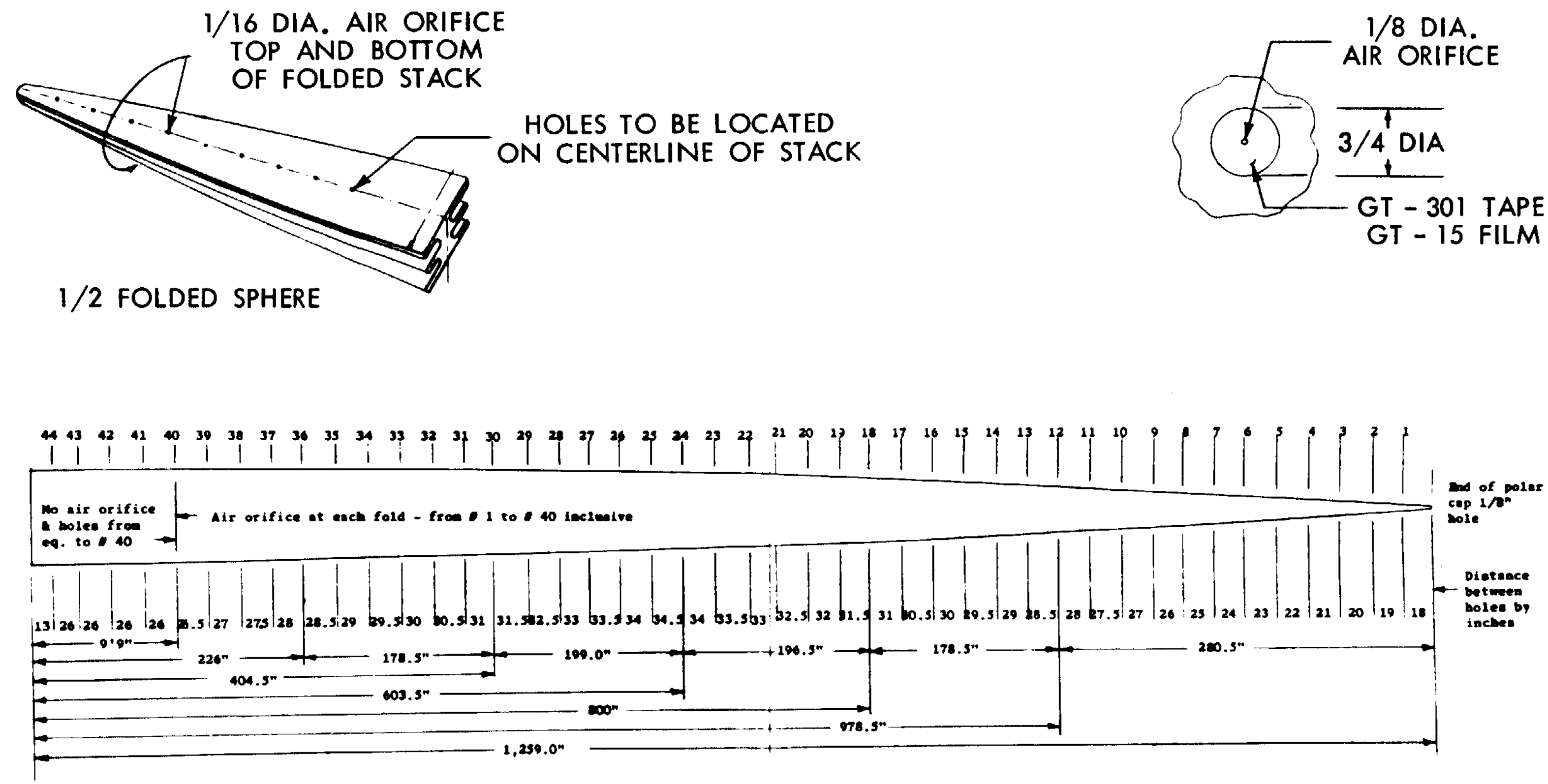


Figure 3-36. Installation of Air Evacuation Holes

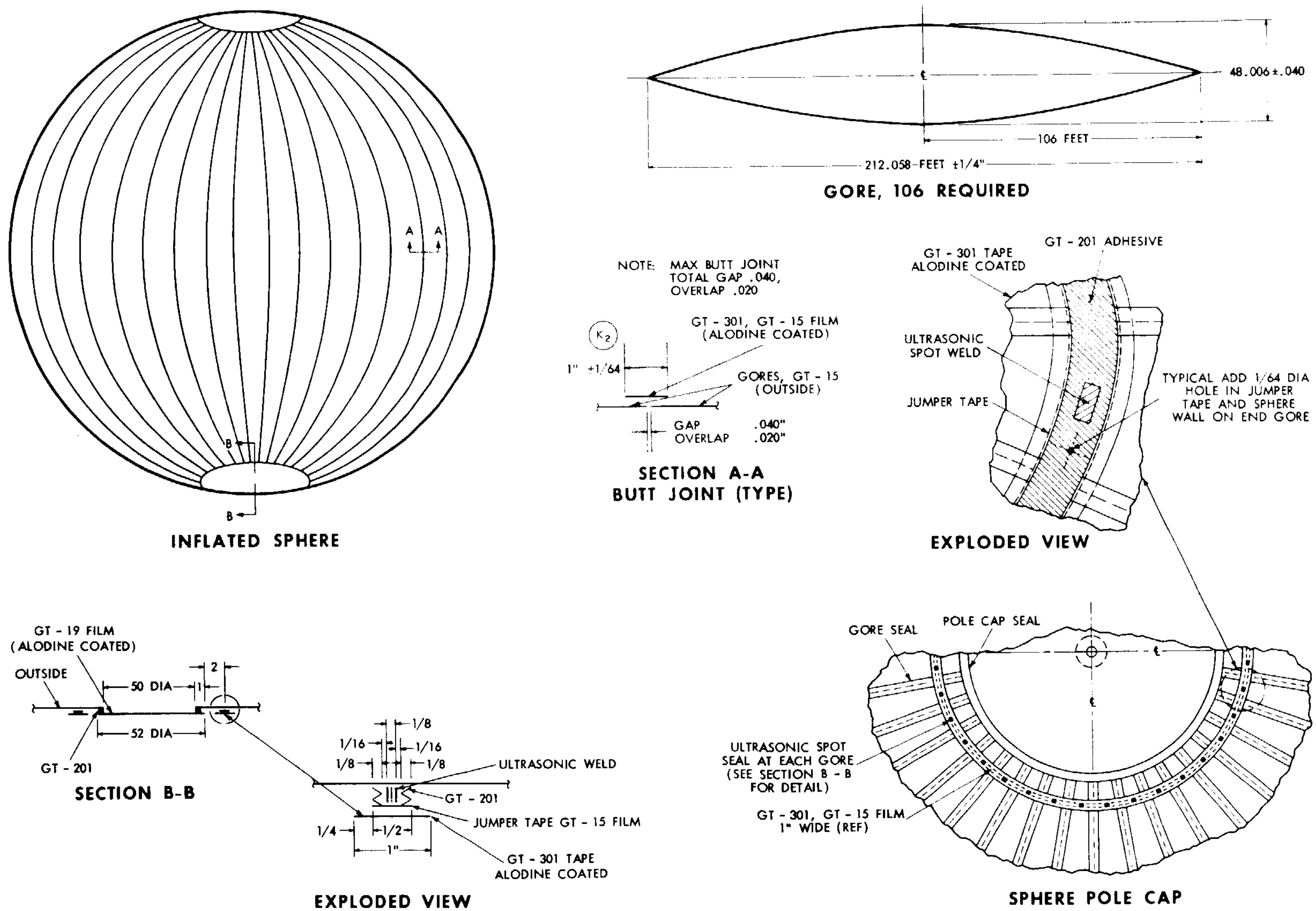


Figure 3-37. Electrical Continuity Jumper Strip and Pole Cap Installation

SECTION 4

SYSTEMS INSTALLATION

4.1 BEACON INSTALLATION

Instrumentation was installed on flight units for tracking and for transmittal of telemetry data regarding internal pressure and skin temperature of the sphere. Each flight unit had two complete and independent sets of instruments, each weighing 6 pounds, mounted 180 degrees apart on the equator (Figure 4-1) and on a centerline with the air evacuation holes longitudinal to the gore length.

Each set of instruments (Figures 4-2 and 4-3) consisted of a transmitter, with built-in pressure sensor, a temperature sensor, four solar panels, and two battery packs which were integral with the transmitters. The solar panels and transmitters were attached to the satellite skin with double-coated (both sides pressure sensitive) Permacel P-10 Mylar tape. Leads and sensors were attached with GT-301 heat sealable adhesive. The high-temperature pressure-sensitive tape had been qualified previously through testing and with attachment of instruments to Echo I. The transmitter was connected to the solar panels by flexible circuits, laminated in Teflon. Electrical connections and electronic checkout of the instrumentation was accomplished during installation on the spheres.

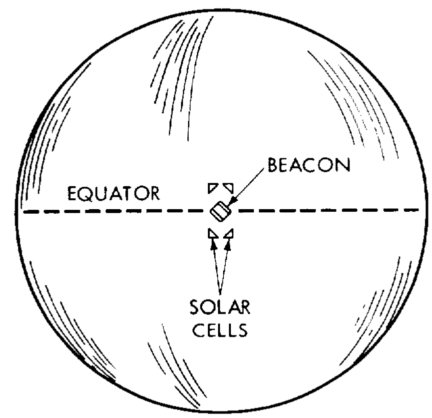


Figure 4-1. Location of Beacon Instrumentation

Scuff pads, fabricated from Alodine-coated GT-16 material, were attached with double-sided pressure-sensitive tape directly opposite the transmitter, solar panels, and other objects extending above the surface of the sphere. These scuff pads prevented damage to the sphere skin due to relative motion between the instruments and the folded sphere skin in contact with them.

The Vita-Var coated GT-15 thermal balance patches, for providing thermal control to the instruments, were also attached with double-sided pressure-sensitive tape. Figure 4-2 shows the location of the scuff pads and thermal balance patches.

Beacon instrumentation was installed on sphere 17 on December 20, 1963, and on sphere 18 on January 6, 1964.

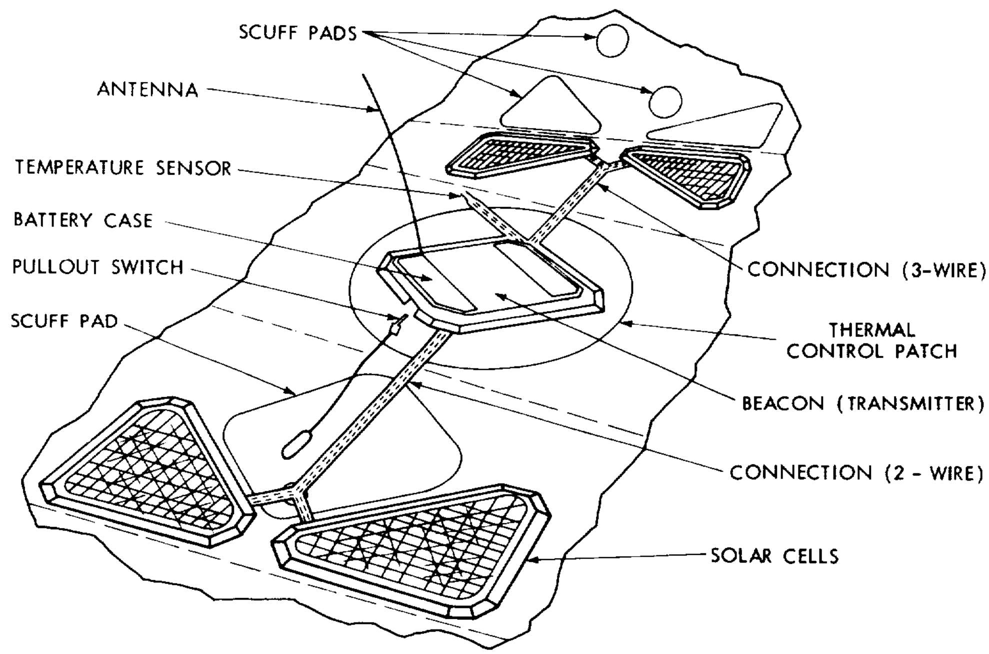


Figure 4-2. Beacon Instrumentation Diagram

4.2 INFLATION SYSTEM INSTALLATION

Because the objective throughout the Echo II program was the inflation of a sphere under space conditions, continued emphasis was given this aspect throughout the sphere development and production phases. The two suborbital tests, AVT-1 and AVT-2, failed to meet the program objectives owing to unsatisfactory inflation systems. The AVT-1 inflation system failed to perform satisfactorily because the inflatant acetamide, which was dusted over the inside surface of the sphere, sublimed too rapidly causing the sphere to rupture. The AVT-2 inflation system failed because sublimation of the benzoic acid dusted over the inside surface did not provide sufficient internal pressure to stress the sphere skin sufficiently.

4.2.1 INITIAL INFLATION SYSTEMS

The inflatant materials were chosen to achieve the proper inflation pressure and to have characteristics of moderate to low toxicity. The initial material chosen was acetamide with a molecular weight of 59 and a vapor pressure of 1 mm Hg at a calculated sphere temperature of 65° C. A highly colored fluorescent melamine dye (Lawter Chemical Company, Hi-Vis orange) was included with the subliming material to provide a tracer in case of a rupture in either the vacuum initial deployment (VID) tests or the AVT tests. With the indication that acetamide gave too rapid a deployment, benzoic acid with a molecular weight of 122

Figure 4-3. Installing Beacon Instrumentation

and a vapor pressure of 1 mm Hg at 96° C was selected and used for the AVT-2 test. Vapor pressure curves for acetamide and benzoic acid are shown in Figure 4-4.

In addition to the inflatant compound, other possible sources of materials that would vaporize were carefully scrutinized, and the ink and Alodine coatings were tested to determine the amount of water and other volatile materials which might be released at the temperature and pressure conditions anticipated in space. Extensive studies of the moisture content of the acetamide were not made, although there is some evidence that slight amounts of moisture were picked up during the fine grinding of the material before its use. During the installation of the acetamide, however, dehumidifiers held the moisture content of the sphere-handling area to less than 50 percent. Although the presence of moisture in acetamide would increase its initial vapor pressure, the effect would not be major because the water exists as a solution and would be expected to exert its vapor pressure only to the extent of its mole fraction. Melting point determinations indicated that the amount of moisture present was probably less than 1 percent. Benzoic acid (Fisher Scientific Resublimed Reagent Grade) indicated moisture contents below about 0.04 percent. This maximum value occurred in only one test out of 20. Tests conducted on the melamine dye indicated approximately 1 percent weight loss on heating for 1 hour at 250° F, but only 0.6 percent was lost when the dye was exposed to 1 mm Hg for 16 hours.

During the program, heaters were installed in the canister evacuation tank to enable controlling temperature should complete baking of the canister and its contents at elevated temperature be required. A test of the system indicated that heating to 100° C was feasible.

The inflatant powder and dye were mixed prior to installation in the sphere. Technicians placed along the length of the folded sphere dusted the powders on the internal surface of the sphere at each pleat fold with cloth dusting bags.

4.2.2 CONTROLLED INFLATION SYSTEM

To eliminate the problems encountered with the AVT-1 and AVT-2 tests, a controlled inflation system (CIS) (reference 12) was designed and developed (reference 13) for installation in the orbital sphere. The sublimation agent for the CIS was 38 pounds of pyrazole in the form of wafers with a vapor pressure curve as shown in Figure 4-4. The pyrazole was contained in 72 wallet-shaped bags (Figure 4-5), which had solid outer surfaces and perforated inner surfaces covering the wafers. The purpose of the perforated covering was to control the rate of sublimation. The bags were sealed closed with a low-melt-point (37° C) adhesive wax. This seal prevented premature sublimation during storage and

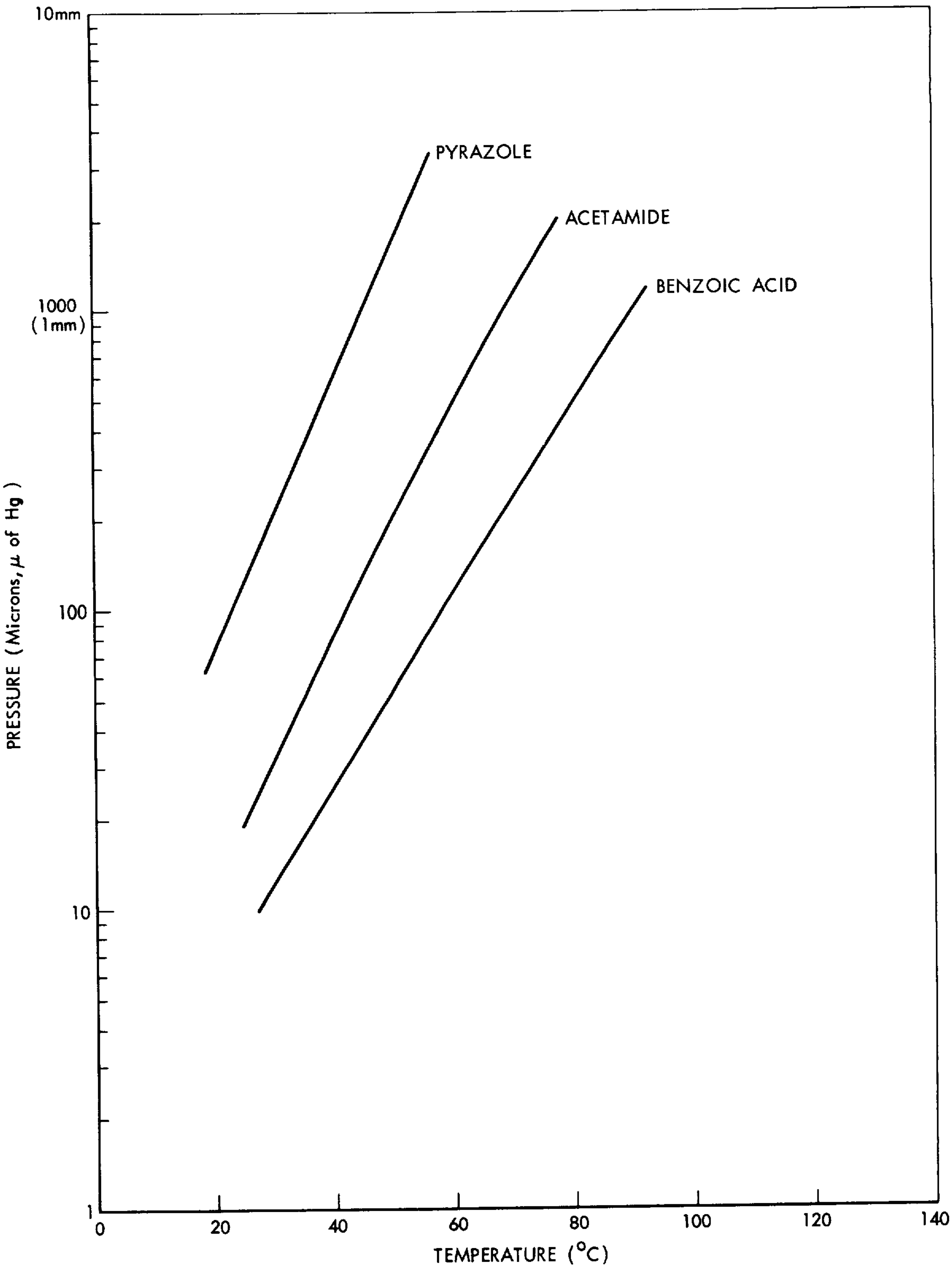


Figure 4-4. Inflation Material Vapor Pressure Curves

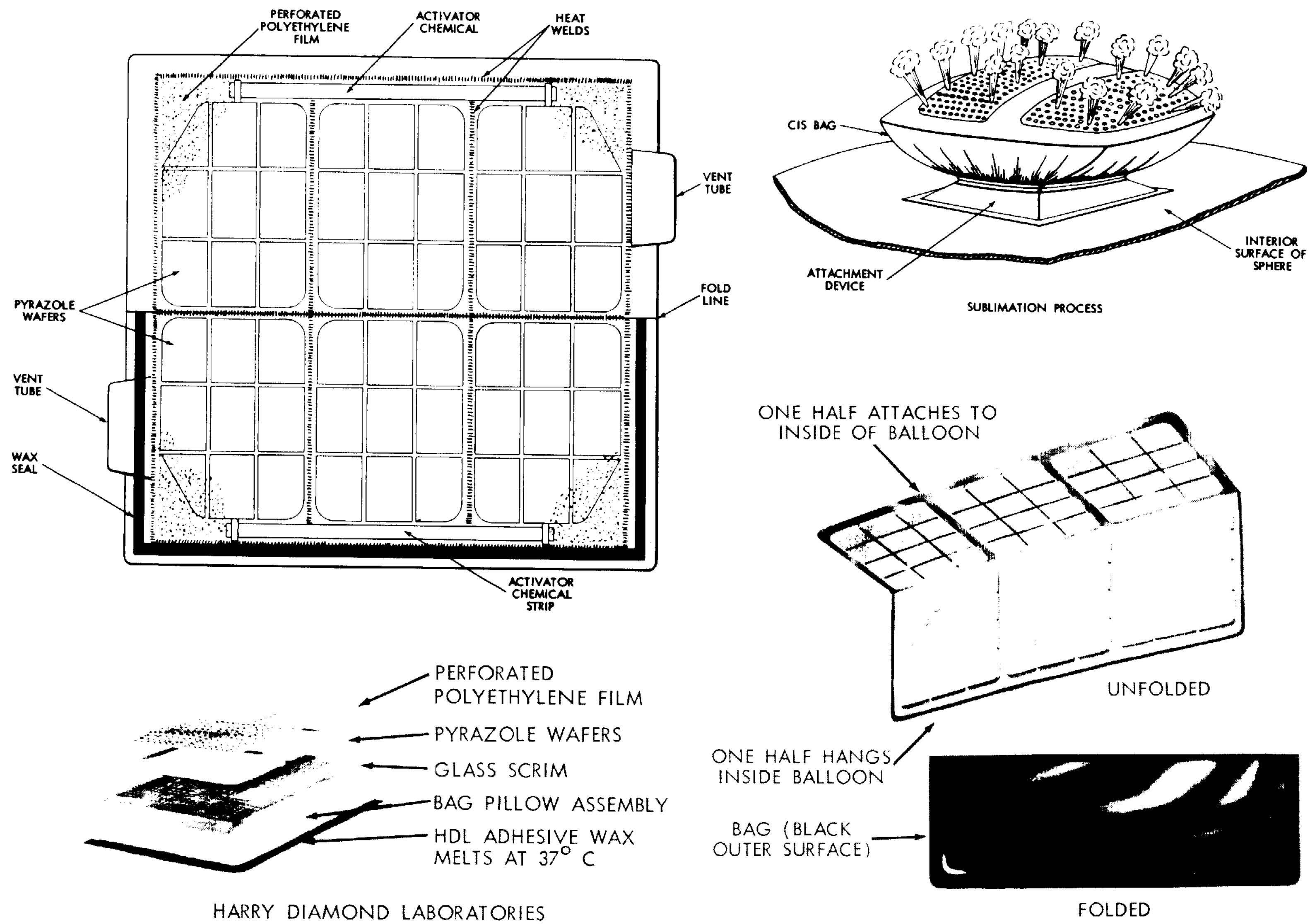


Figure 4-5. Controlled Inflation System Bag

initial deployment, and permitted opening of the bags as the sphere reached steady-state temperature conditions. Two bag sizes were used to accomodate the size of the folds of the sphere. Forty A-size bags 12 by 24 inches and 32 B-size bags 9-1/2 by 25-1/2 inches were installed in the sphere.

The bags were attached to the internal surface of the sphere in a belt around the equator (Figure 4-6) so that no more than two bags were attached to any one gore. The bags were installed in the pleat folded sphere (Figure 4-7) at the locations indicated in Table 4-1. The attachment device (Figure 4-8) was a 1 mil thick polyethylene sheet attached by pressure-sensitive tape to the CIS bag and the sphere wall. The attachment sheet was designed to act as a shock absorber for forces experienced by the CIS bags during deployment and to allow installation without causing deformation to the surface contour of the sphere. The development of the attachment device is discussed in section 4.2.2.1.

TABLE 4-1

Location of CIS Bags in Pleat-Folded Sphere

Pleat No.	Between Fold Nos.	Bag Size
8	41-42	A
10	31-32	B
17	35-36	A
23	27-28	B
28	37-38	A
33	29-30	B
38	39-40	A
40	25-26	B
43	33-34	A
52	32-33	A
55	24-25	B
57	38-39	A
62	28-29	B
67	36-37	A
72	26-27	B
78	34-35	A
85	30-31	B
87	40-41	A

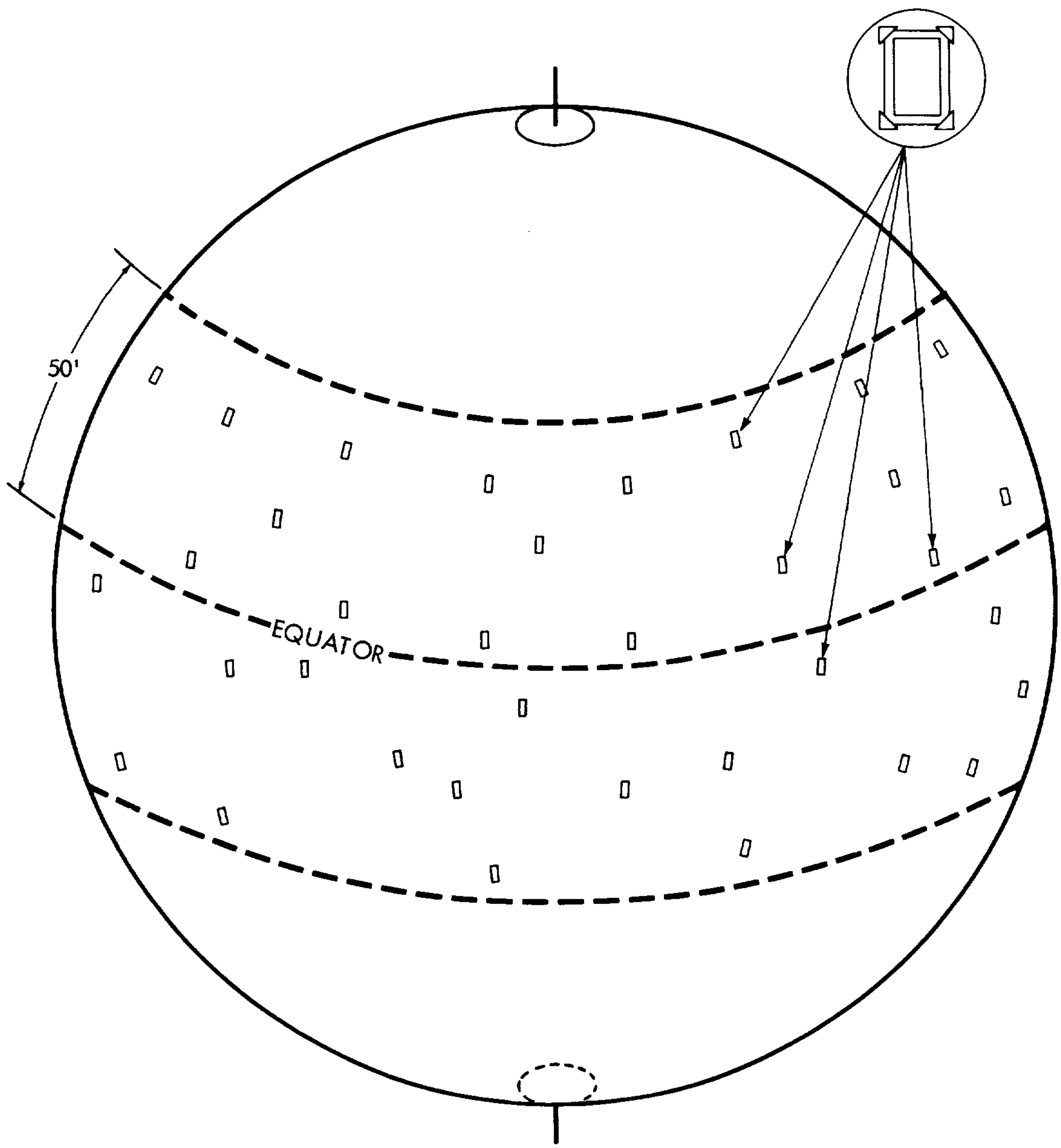


Figure 4-6. Controlled Inflation System Bag Location

Figure 4-7. Installing CIS Bag

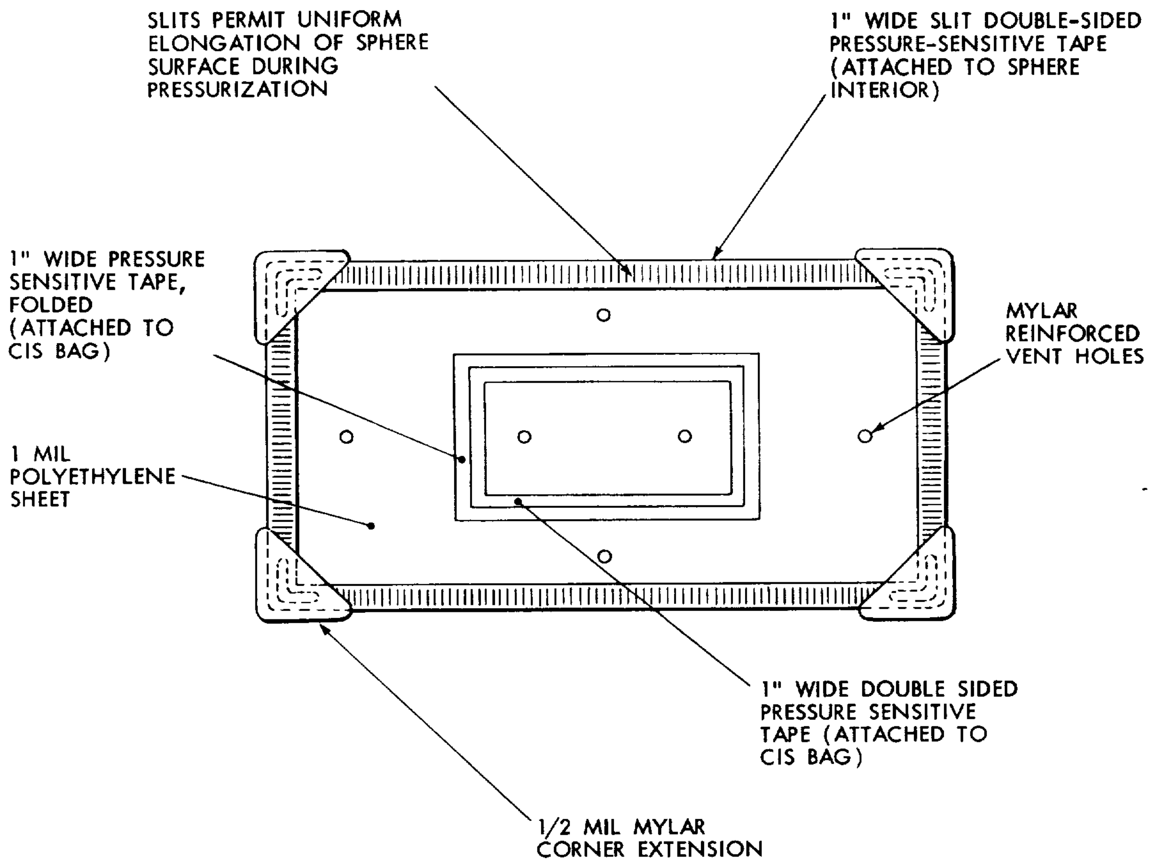


Figure 4-8. CIS Attachment Device

Installation of the controlled inflation system into the sphere was begun 24 hours before canister and sphere evacuation to limit exposure time of the controlled inflation bags to atmospheric conditions. CIS bags were installed in orbital sphere 18 on January 9, 1964, and in standby sphere 17 on December 31, 1963.

4.2.2.1 Attachment Study — Drop Tests

The objective of the CIS attachment study was to develop a simple yet rugged method to fasten the CIS bags to the Echo II sphere. The system was to be compatible with the packed sphere and was in no way to affect detrimentally the sphere during and after inflation. Seven basic attachment designs were generated. Preliminary tests indicated that four of these designs (Figure 4-9) were acceptable for environmental testing to simulate deployment. Several models of each design were fabricated and tested under vacuum in the GSFC Dynamic Test Chamber (DTC). Twelve tests were conducted (references 14 and 15), seven in the first series and five in the second.

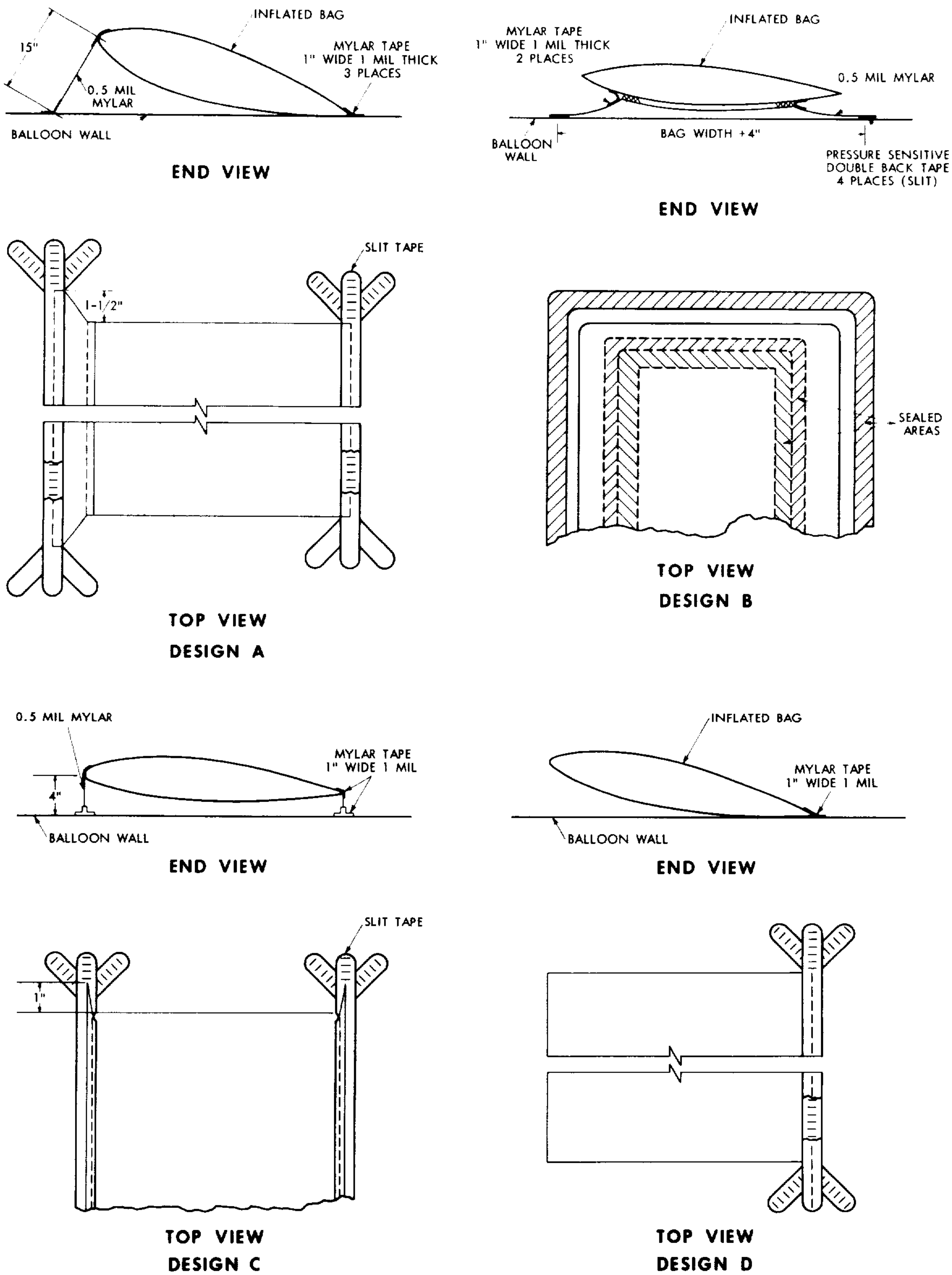


Figure 4-9. Proposed Attachment Designs

The first series of tests used the setup shown in Figure 4-10. The test gores of GT-15 material were 8 feet wide (two 4-foot widths taped together) and about 46 feet long. The ends of the gores were suspended from two 4-inch diameter adjustable support rollers attached to hard points on the DTC wall. The rollers provided adjustment of the gore lengths to obtain the proper test conditions. Four attachment points were provided across the center width of the gores for raising to the drop height of 24 feet. These attachments were made with 6-lb monofilament nylon test line to an overhead solenoid release device. Actuation of the solenoid released all four attachment lines simultaneously. Drop heights were adjusted with a pulley-cable-winch arrangement.

Velocity measurements were obtained with a perforated-tape photodiode cell apparatus. Figure 4-11 shows a typical velocity vs distance of travel plot for this series of tests. Acceleration measurements were obtained with a single axis Statham strain gauge accelerometer (+10 g range) attached to the gore. The outputs from the accelerometer were recorded on both a CEC oscillograph and a magnetic tape recorder.

Two Fairchild cameras obtained high-speed motion picture coverage of the test. One camera was positioned at the lower DTC camera port for broadside coverage of the last 10 feet of the drop. The other camera was positioned at the camera port on the dome of the DTC for a top view of the bag attachment area over the full drop. Framing rates for these tests varied between 500 and 1400 frames per second. The photo coverage yielded useful qualitative information for interpreting gore behavior during the tests. Ambient temperature in the vicinity of the impact area was monitored by a copper constant (No. 30 wire) thermocouple and a Brown recorder.

Evacuation of the DTC was started about 3 hours before the test. The countdown was started at T-10 seconds followed by turning on photo lights, cameras, velocity pickup, and accelerometer recorders. The solenoid was actuated releasing the gore with CIS bags attached. The DTC was vented about 5 minutes after the drop and achieved atmospheric pressure in about 1 hour. Table 4-2 gives the results of the seven tests. Designs A, C, and D exhibited certain weaknesses as bag attachments. Design B survived the tests satisfactorily. However, the test setup was determined to be inadequate because of the complicated dynamic behavior of the gores during the drop. In addition, maximum velocities did not necessarily correspond to the instant of maximum gore travel. This discrepancy was caused by the excessive droop of the gores in the suspended position. Although the problem was recognized after the third test, to maintain continuity throughout this series of tests it was decided not to change the setup. It was recommended that the test setup be revised to eliminate the slack in the suspended gore for the second series of tests, which provided further information on designs B and D.

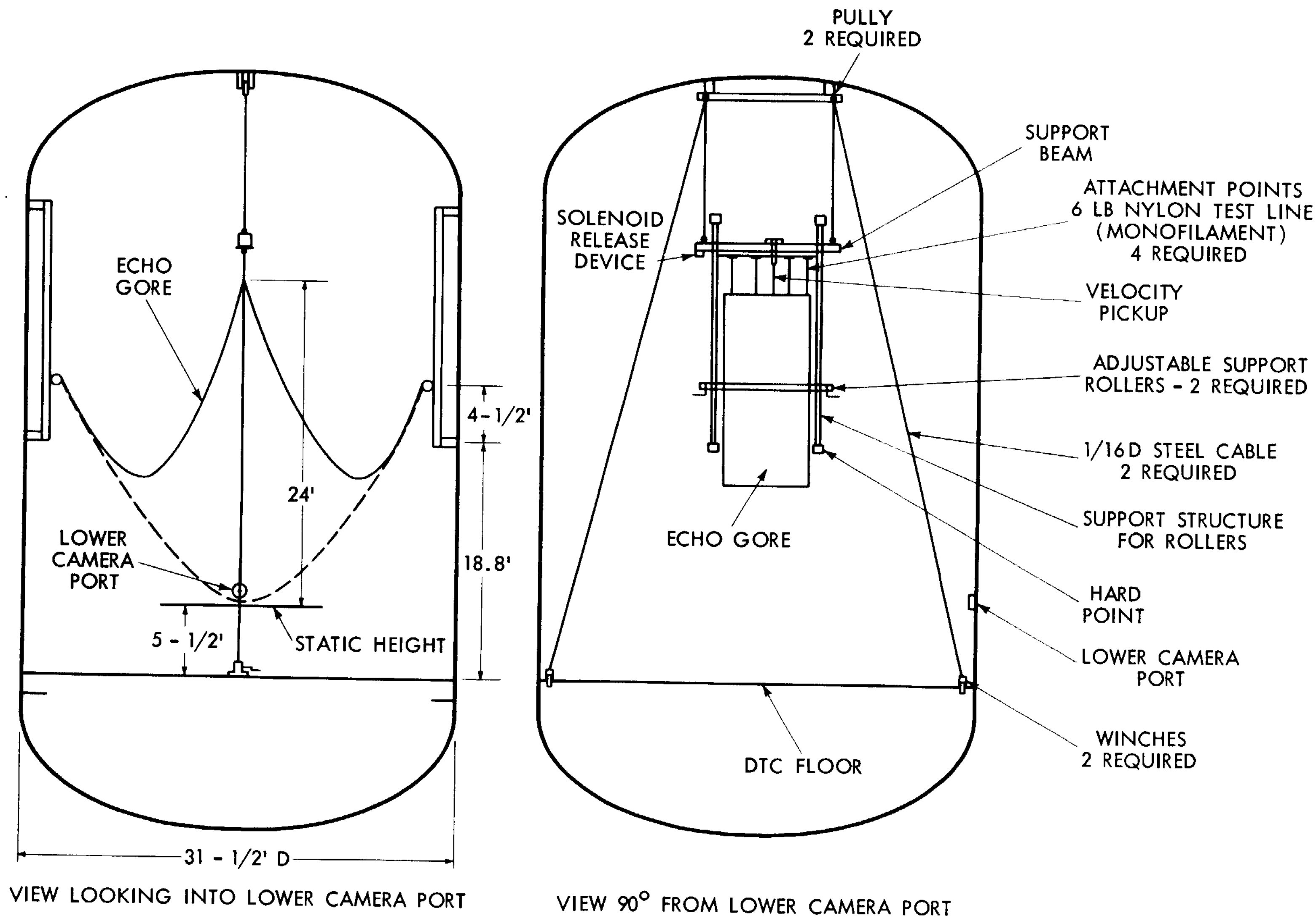


Figure 4-10. Test Setup in Dynamic Test Chamber (DTC), First Series

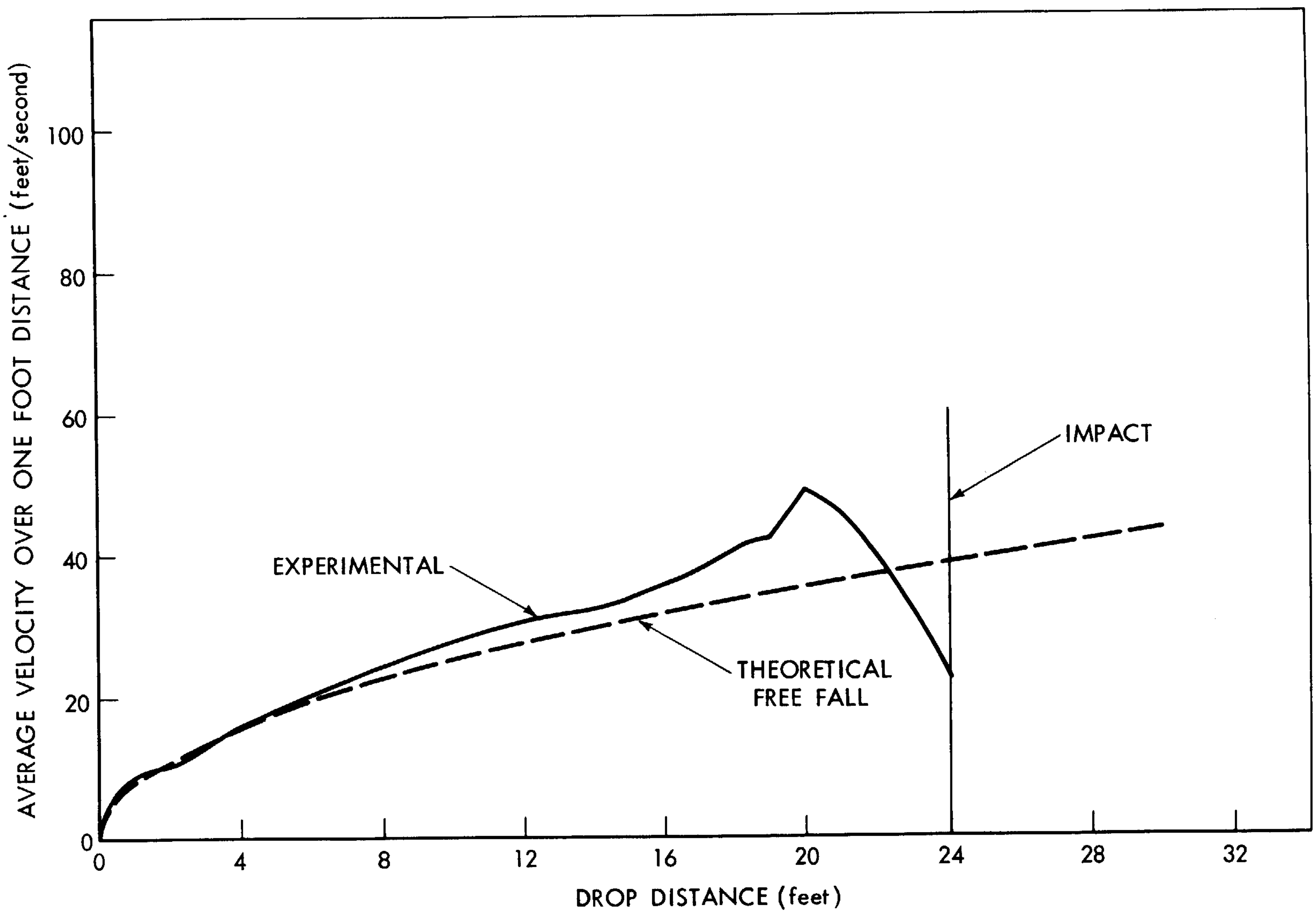


Figure 4-11. Typical Velocity vs Distance Traveled, First Series

TABLE 4-2

Results of First Series of Drop Tests

Test No.	Bag* Attach.	Vacuum (microns)	Maximum Velocity (ft/sec)	Maximum Temp. in DTC (°C)	Remarks
1	DIT	26	39	37	Wrinkled gore at attachment point ends
2	DOT	7	Not Measured	43	Wrinkled gore at attachment point ends
3	AOT BOT	12	48	44	Partial failure of AOT attachment
4	AIP BIT	20	48	39	AIP failed through gore
5	CIP DIP	27	61	48	Gore failed at splice
6	COP DOP	19	49	48	Both designs failed at attachment to gore. Gore was suspended overnight before test was run
7	BOP DOP	16	55	50	DOP attachment failed on second bounce

*Large bags were used for these tests (approximate weight - 1 lb).

Code:

A - Design A (See Figure 4-9)
B - Design B (See Figure 4-9)
C - Design C (See Figure 4-9)
D - Design D (See Figure 4-9)
I - Bag attached to inside of balloon (top of gore)
O - Bag attached to outside of balloon (bottom of gore)
P - Bag oriented parallel to the gore's 46-foot dimension
T - Bag oriented transverse to the gore's 46-foot dimension

The second series of tests was conducted under improved simulated inflation dynamics in the DTC to further evaluate slightly modified designs B and D (Figure 4-12). Figure 4-13 shows the test setup, which was basically the same as in the first series except for the gore suspension. The slack was removed from the gore and four double attachment points were provided across the center width of the gores for raising to the drop height. A spreader bar arrangement (Figure 4-14) was used to eliminate bag distortion in the suspended position. Figure 4-15 shows a typical velocity plot for this series. No accelerometers were used in this series since no useful data was obtained with them in the first series. Photo coverage was the same as before. Five drops were made from a height of 25 feet. Table 4-3 gives results of the tests. Design D failed to survive the one test in which it was included. The other tests involved design B with various thicknesses of polyethylene in the attachment. The attachment fabricated from 1 mil polyethylene provided a method of controlled failure for these tests. The 2 mil polyethylene attachment survived all tests without indication of failure. Evaluation of the test results indicated that the bag attachments were subjected to some degree of overtest — about 50 percent greater than conditions expected during deployment.

Figure 4-8 shows the attachment design ultimately used in the orbital sphere. The attachment of 1 mil polyethylene was chosen to provide a controlled failure or fail safe feature (Figures 4-16 and 4-17). The attachment was slightly larger than the corresponding CIS bag. Vent holes provided a means for evacuating air which may be entrapped during installation of the CIS into the sphere. These vent holes were reinforced to eliminate stress concentrations. The double sided pressure-sensitive tape used to mate the attachment device to the sphere skin was slit at 1/4 inch intervals to permit elongation of the sphere skin during the pressurization and rigidization sequence. Reinforcements of 1/2 mil Mylar were provided at the corners of the attachment device to preclude puncture of the sphere skin by a corner of the CIS bag.

4.2.2.2 Inflation Bag Deformation Study

An investigation was made to determine the extent of and to eliminate local deformation to the Echo II sphere material caused by pressurization of CIS bags after sublimation of the pyrazole inflatant. Deformation or nonsphericity in the Echo II surface would degrade reflection of electromagnetic radiation from the surface. Pressurization of the bags would be caused by expansion of a chemical installed in a bag compartment which was designed to force the bag open after melting of the adhesive wax.

A full-size CIS bag was attached to a 4 foot by 4 foot piece of Echo II material after the bag had been opened and the pyrazole inflatant removed. The area of

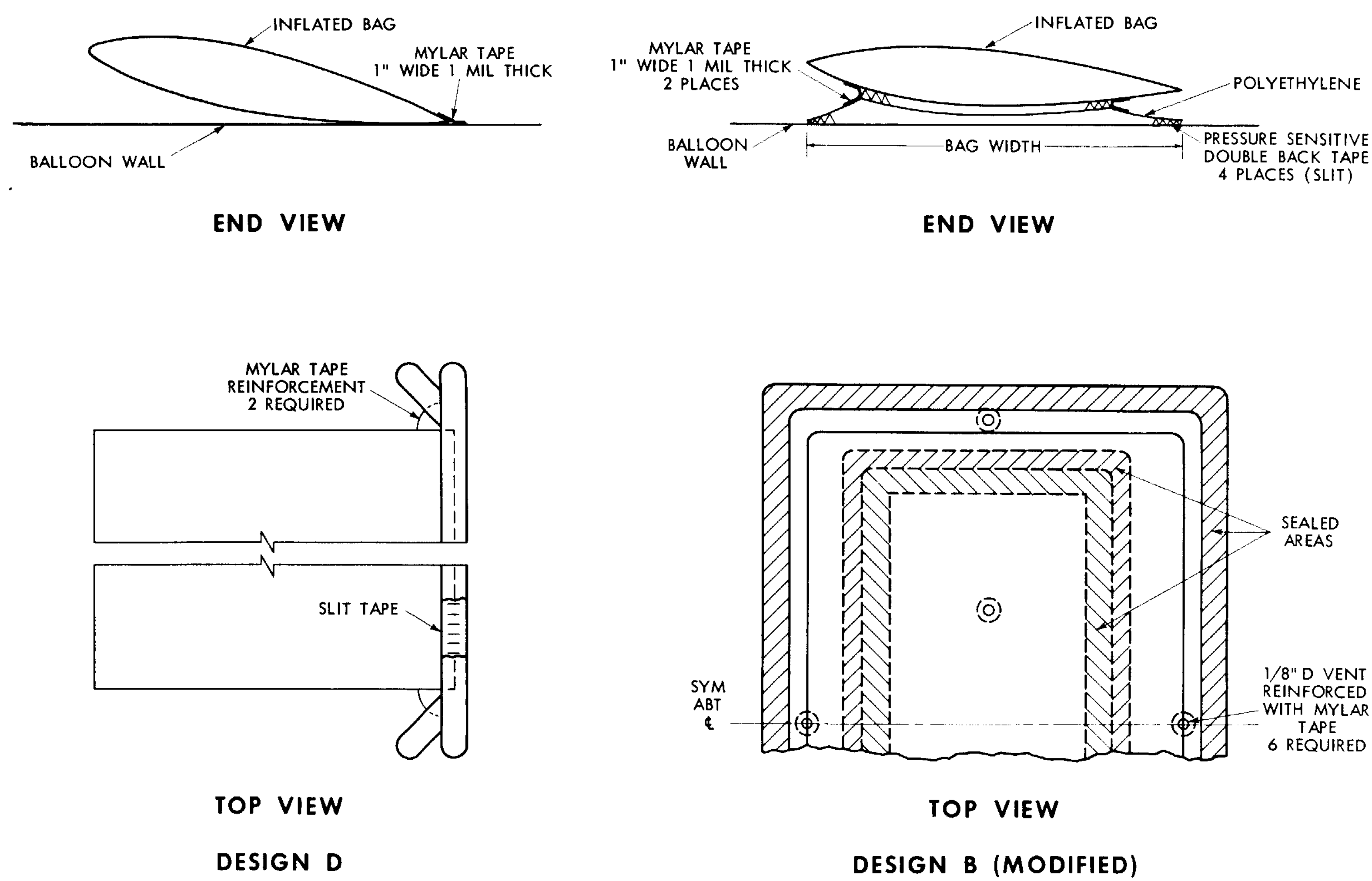
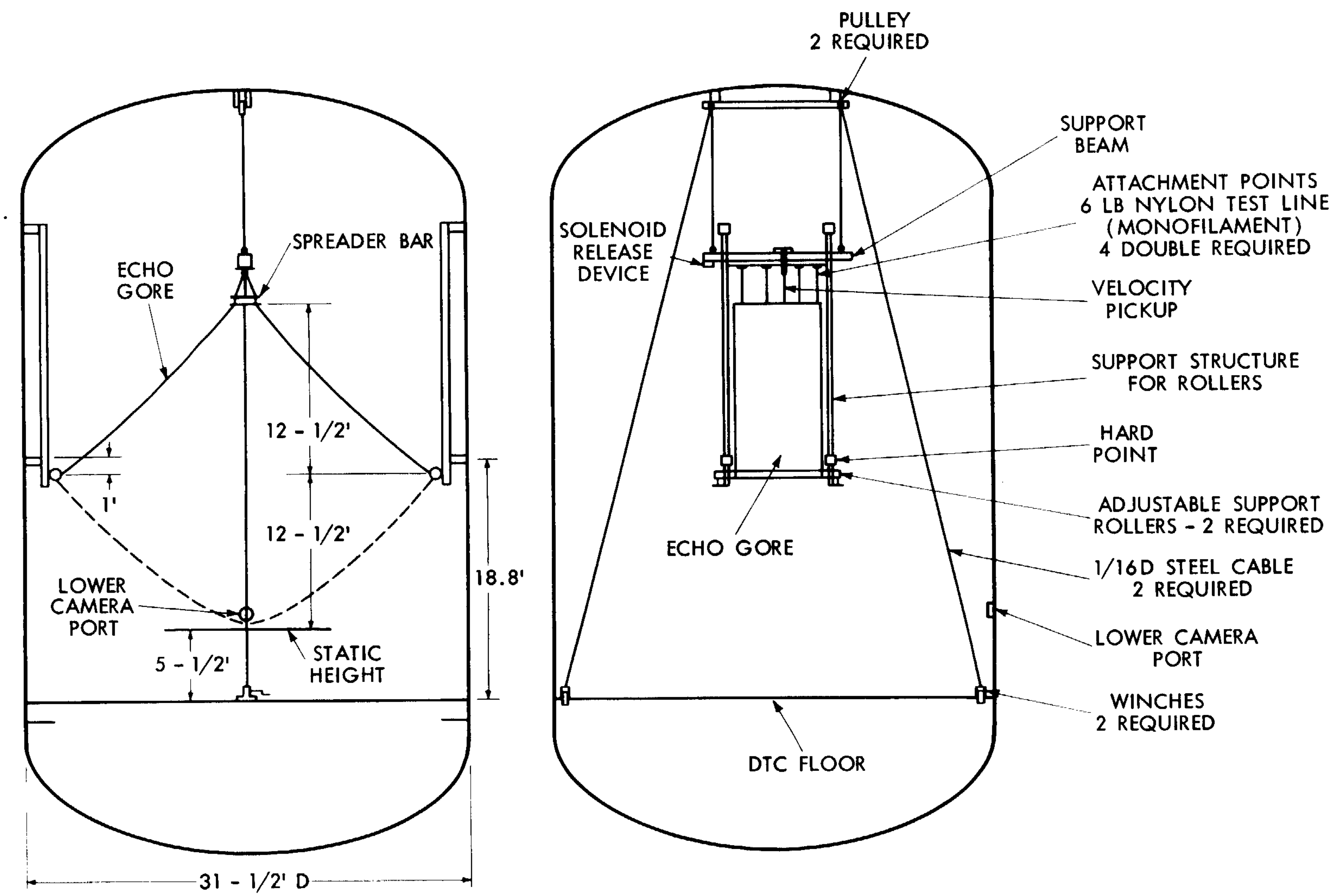


Figure 4-12. Modified Attachment Designs



VIEW LOOKING INTO LOWER CAMERA PORT VIEW 90° FROM LOWER CAMERA PORT

Figure 4-13. Test Setup in Dynamic Test Chamber (DTC), Second Series

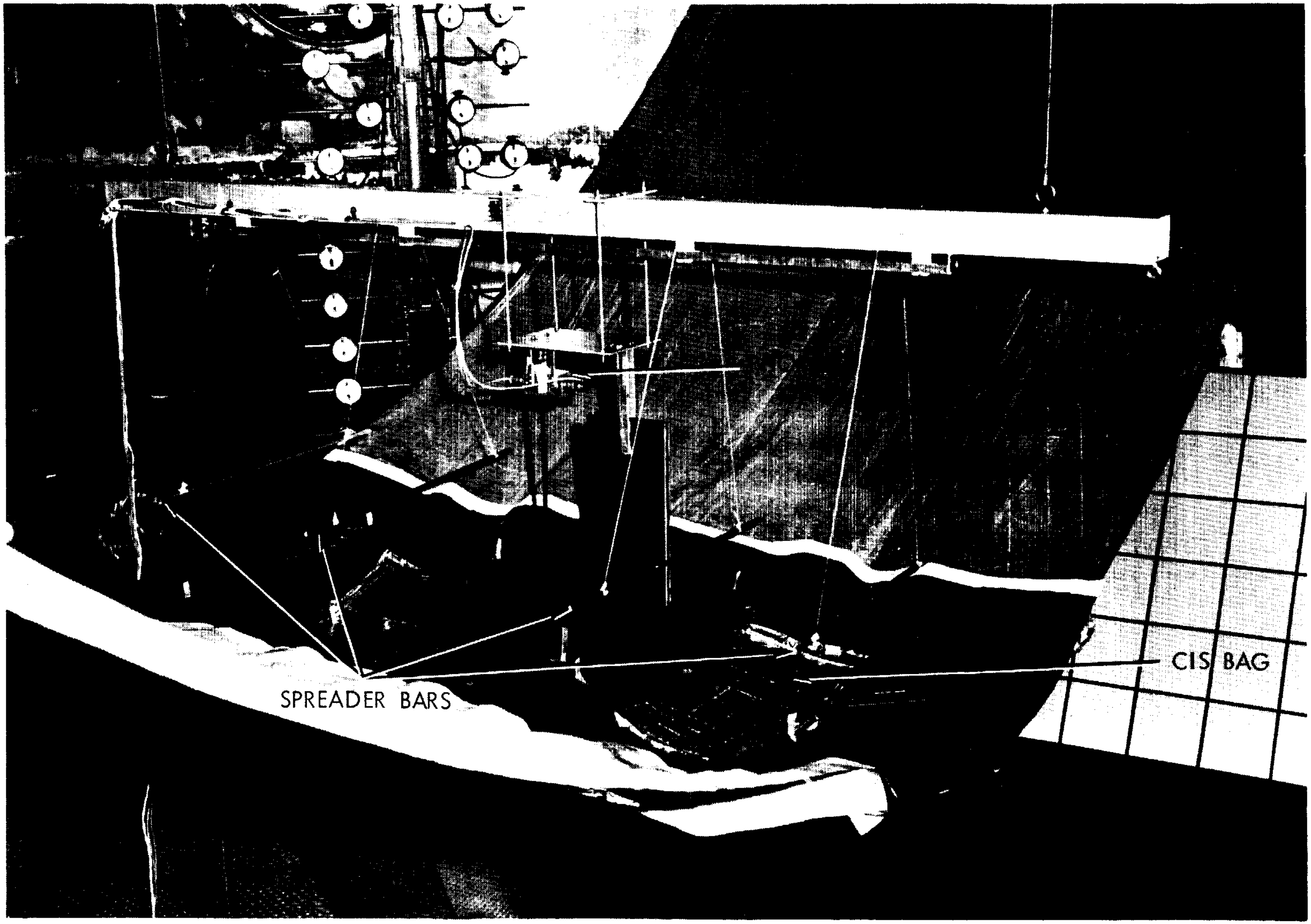


Figure 4-14. CIS Suspension System Showing Spreader Bar Arrangement

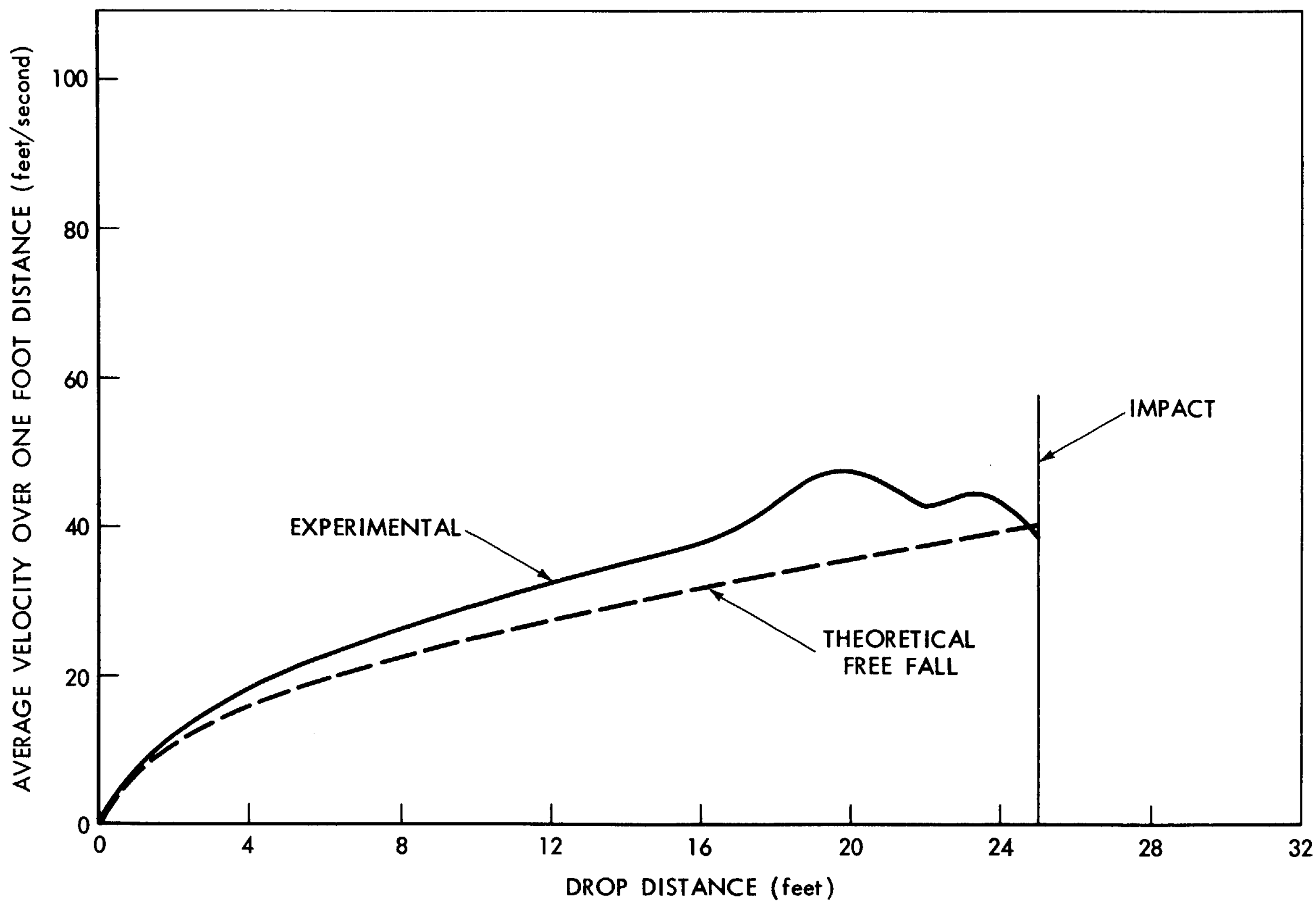


Figure 4-15. Typical Velocity vs Distance Traveled, Second Series

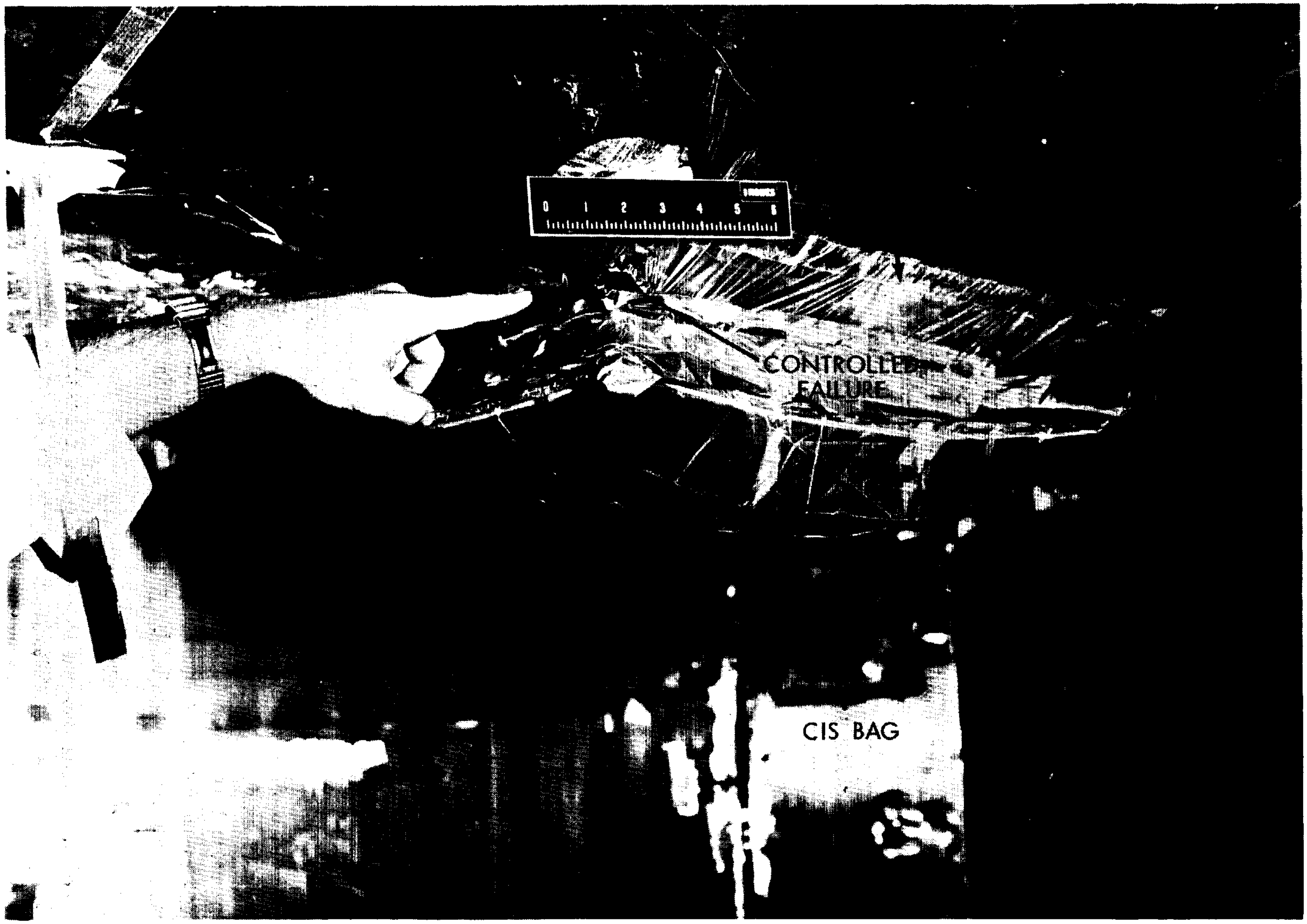


Figure 4-17. CIS Attachment Controlled Failure

the attachment in contact with the sphere skin was 12 by 24 inches. The area of the attachment in contact with the CIS bag was 5 by 17 inches. The test specimen was suspended as shown in Figure 4-18.

The Echo II material was biaxially stressed to 1 pound per linear inch and the CIS bag inflated to 5 mm Hg and 10 mm Hg. The Echo II material was then relaxed with the CIS bag pressure at 10 mm Hg. Considerable deformation to the material at CIS bag pressures of 5 and 10 mm Hg was noted visually at the stress of 1 pound per inch. When relaxed, the deformation was more pronounced.

To eliminate this condition, the area of attachment in contact with the CIS bag was reduced to 5 by 10 inches. The area in contact with the sphere material was kept at 12 by 24 inches. The series of tests was repeated with the modified bag attachment. Essentially all of the deformation to the material sample was eliminated under all test conditions because of the change in attachment design. The following summarizes the test conditions and results.

Test No.	Skin Stress (lb/in)	Bag Pressure (mm Hg)	Deformation
1	1	0	Yes
2	1	5	Yes
3	1	10	Yes
4	0	10	Yes
5 (modified attach.)	1	0	No
6 (modified attach.)	1	5	No
7 (modified attach.)	1	10	No
8 (modified attach.)	0	10	No

4.3 FLUORESCENT DYE INSTALLATION

Simultaneously with controlled inflation system installation, 10 pounds of red fluorescent melamine dye was distributed over the entire inner surface of spheres 17 and 18 (Figure 4-19). Dye was installed to preclude any blocking which might have been caused by residual traces of adhesive in seal areas, to provide an optical tracer in the event of rupture during deployment, and to distribute residual air inside the sphere to facilitate a more uniform initial deployment.

The need for using the dye to eliminate the blocking problem was demonstrated in a series of tests on Echo II material. Tests were performed on ink coated material containing traces of adhesive coated with dye, ink coated material

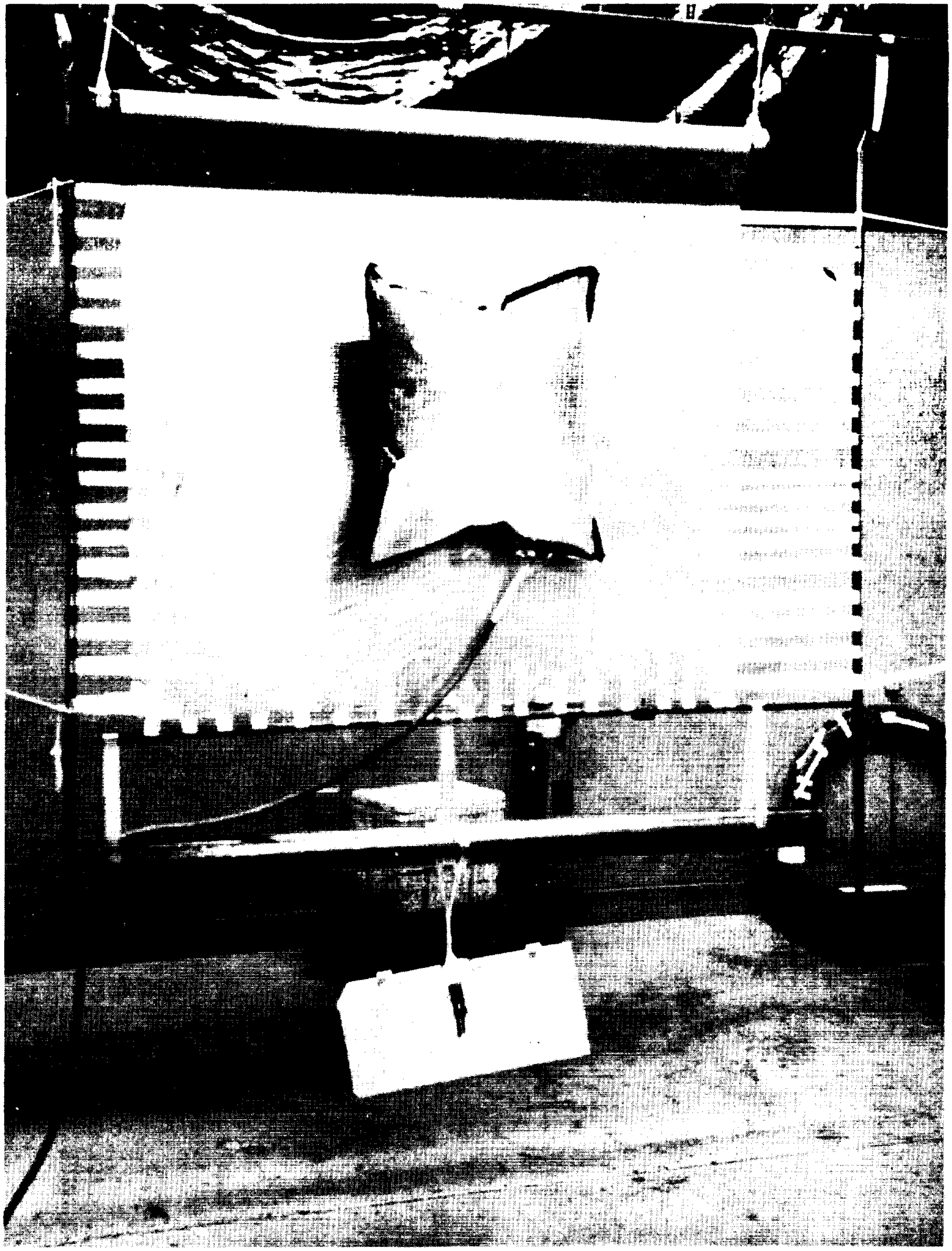


Figure 4-18. Deformation Study Test Setup

Figure 4-19. Fluorescent Dye Installation

containing traces of adhesive without the dye coating, and plain ink coated material. The adhesive applied to the samples existed in two conditions: (1) as applied and (2) wiped with a methylene chloride (solvent) wetted cloth. The dye was then added to samples in various amounts simulating 4, 6, 8, and 10 pounds covering for the full size sphere. For the 72 square inch samples tested the following table relates the equivalent weights of dye added.

Wt. Dye on Sample (grams)	Wt. Dye in Sphere (lbs)
0.0158	4
0.0237	6
0.031	8
0.0395	10

The samples were folded accordian fashion and placed under 30 psi pressure for 24 hours. The samples were then removed and tensile tested in an Instron tester at a rate of 50 inches per minute. Table 4-4 indicates the forces required to separate the folded samples for the various test conditions.

As a result of these tests it was decided to apply 10 pounds of dye to the internal surface of the sphere. The dye was dusted onto the internal surface with folded cheesecloth pads while the spheres were in the pleated condition. The pleat folds were exposed one at a time for the dusting operation.

Fluorescent dye was applied to the backup flight sphere 17 on December 31, 1963 and to flight sphere 18 on January 9, 1964.

Table 4-4

Tensile Test Results of Blocking Study

Sample Condition	No Adhesive No Dye (grams)	Adhesive (grams)				
		No Dye	4# Dye	6# Dye	8# Dye	10# Dye
Sample not cleaned with methylene chloride	3 3 3	124 130	110 195 165	130 146 193	130 80 98	105 93 146
Sample cleaned with methylene chloride		74 104	84 55 72	150 168 100	90 18	6 8

SECTION 5

PACKAGING AND EVACUATION

5.1 CANISTER PACKING

5.1.1 PACKING FACTOR DETERMINATION

Sphere 1 was fabricated and designated for canister packing tests to establish the packing factor and to permit freezing canister design.

Two plastic canister sets were used in the tests. One had a packing factor of 2.5 and the other 3.0. Attempts to pack the sphere in the 2.5 canister failed because of false pleats and folds adding to the stack height. Several attempts were required with the 3.0 factor plastic canister employing slight rotation between each fold to utilize as much canister volume as possible. The canister design was frozen at a diameter of 39.6 inches and total height of 28.8 inches giving a packing factor of 3.0. Reference 16 lists the reports and drawings generated during the development of the canister.

5.1.2 ROTATING FOLD METHOD

Preparations for packing were made after completion of final operations such as end-cap installation, electrical continuity jumper strip installation, insertion of inflation system, beacon installation, and final seal. The pleat folds required repositioning after being disturbed from performing the final operations. After straightening the folds, smooth tie boards were secured at each odd numbered gore station to hold the two halves together throughout the folding and packing operation. This precaution prevented yielding or fracturing of the single layer of material on the top of bottom of the stack of pleats. An 8 mil vinyl sleeve was then sealed, enclosing the satellite, and evacuated to 10 inches of mercury for a minimum of 12 hours. A drag cloth was placed under the full length of the sleeved unit to permit easy handling as the sphere was advanced on the table during packing.

Three inclined tables were placed at the north end of the sealing table and the drag cloth windup put in place with one technician on each side to guide the sphere to the packers and to remove the vinyl sleeve. Figure 5-1 shows the equipment setup for the packing operation.

Three operators were stationed on each side of the sealing table to assist in advancing the sphere toward the end of the table. Four operators were assigned to remove the tie boards and to fold the sphere into the canister. Two operators were assigned to handle the vacuum pump and hose.

The bottom canister half was positioned on its cart at the end of the inclined tables. A pad of cheesecloth, approximately 6 inches square, was placed over

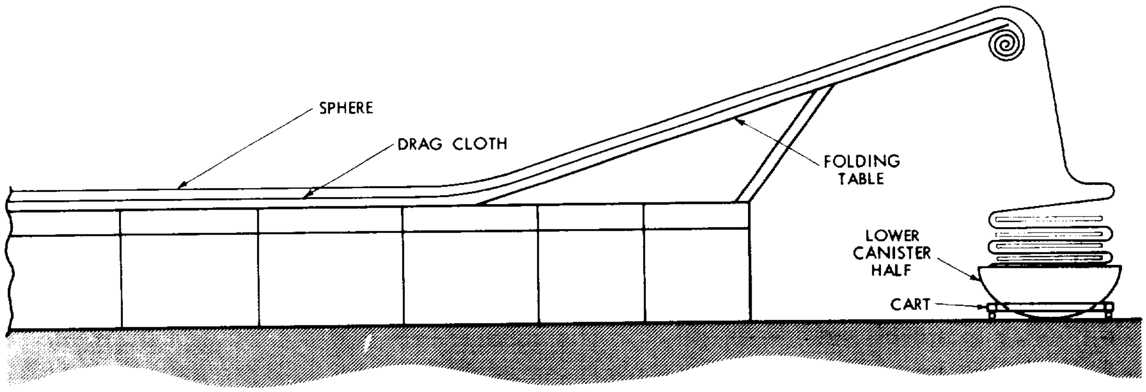


Figure 5-1. Packing Equipment Setup

the airport in the bottom of the canister and a band of foam rubber, 1 inch thick and 8 inches wide, was taped around the inside top edge of the canister. To hold vacuum on the south end of the sphere after the north end of the sleeve was opened, the sleeve was clamped just north of the instrumentation area.

The bottom half of the sphere was packed into the canister rotating the canister 10 degrees before each fold. After nine folds, when the canister had been turned 90 degrees, its direction of rotation was reversed and 18 more folds were made turning the canister 10 degrees in the opposite direction before each fold. The direction of rotation was then again reversed, and the folding continued until the clamp was reached. A second clamp was then attached just south of the instrumentation area. The north clamp was removed, the lanyards to the transmitter switches were armed, and the center (beacon) section folded into the canister. Polyethylene was laid over the packed canister half and six 40 pound weights were placed on top to keep the sphere compressed.

The inclined tables were moved to the south end of the sealing table and the drag cloth repositioned. The turn-over ring was mounted in the plastic canister half and the south half of the sphere was folded into the plastic half by the same method. Figure 5-2 shows several stages of the rotating fold method of packing. The last fold was lifted over the side of the inclined table so that the two canister carts could move together.

A plywood turnover board was then bolted to the plastic canister half. The portable hoist with turn-over brackets lifted the packed plastic canister from its support cart and supported it as it was positioned over the bottom canister half. Figure 5-3 shows a sphere packed by the rotating fold method. All excess equipment was then removed and a 2-foot wide band of vinyl was sealed around the parting area of the two halves. A vacuum pump was then used to evacuate enough air from the sphere to allow the two canister halves to be drawn together.

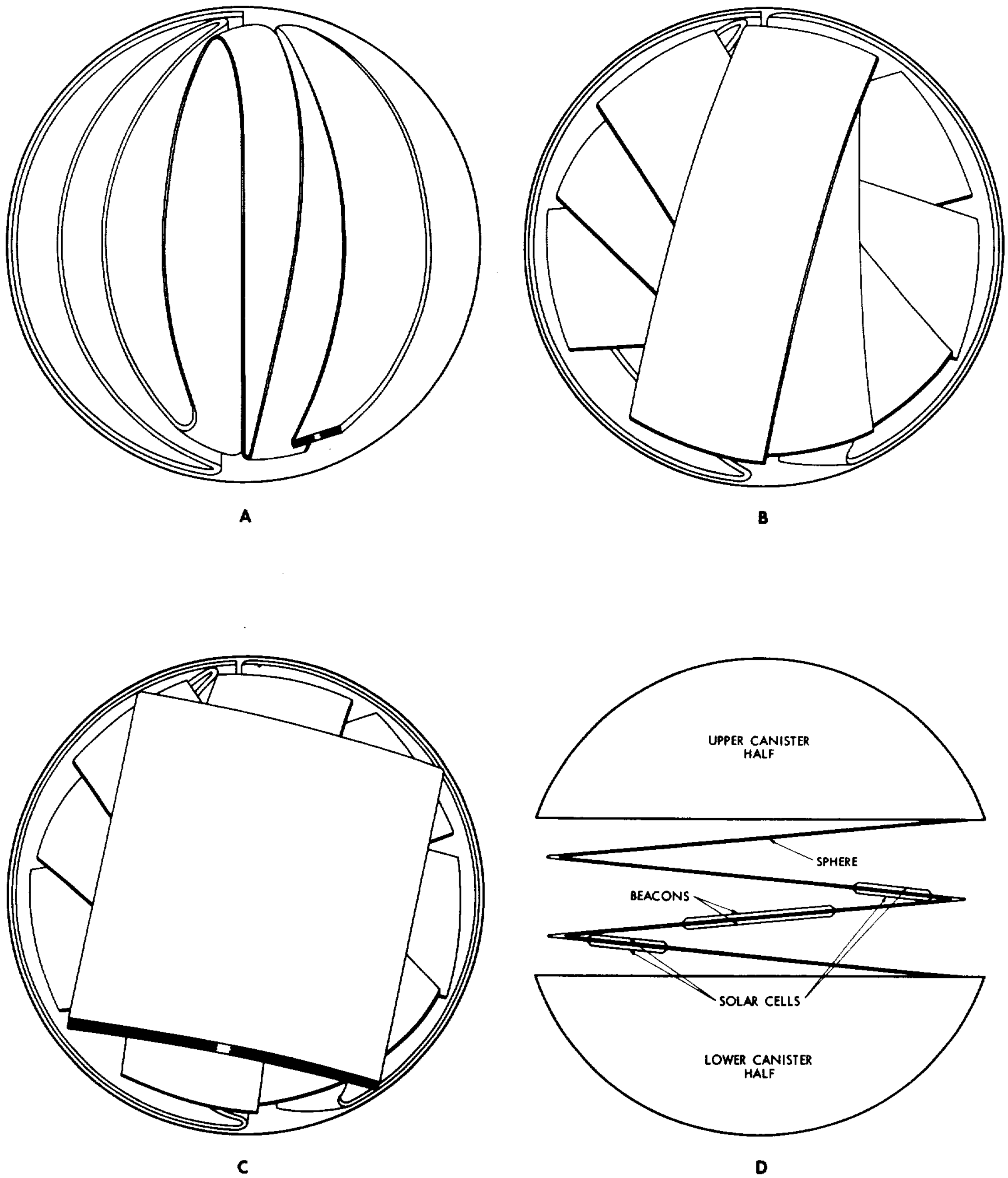


Figure 5-2. Rotating Fold Method of Packing

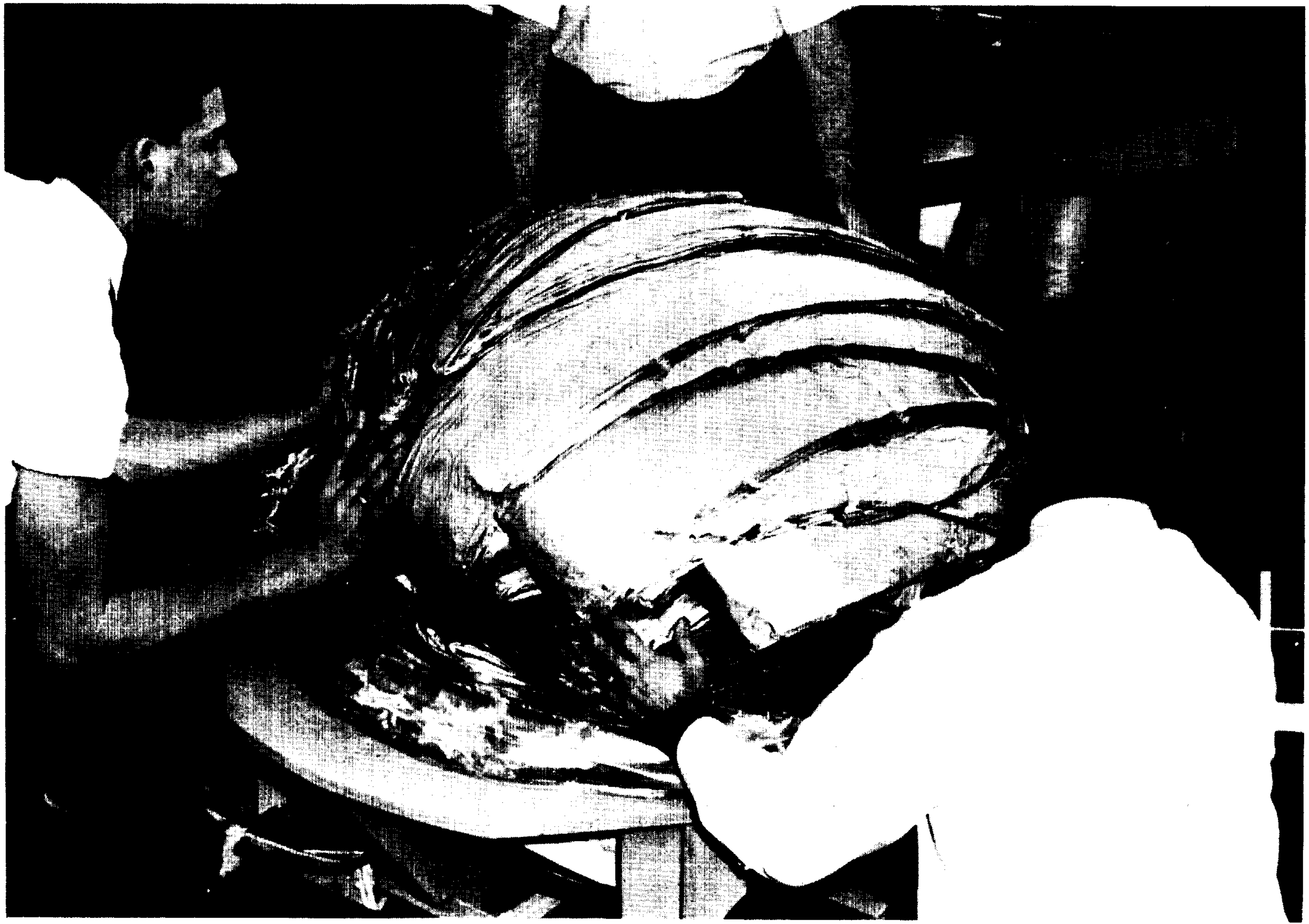


Figure 5-3. Sphere Packed in Canister by Rotating Fold Method

The plastic half canister was then replaced by the magnesium top and the smoke shields were inserted inside the canister around the equator to prevent damage to the sphere upon detonation of the pyrotechnic used to separate the canister halves at deployment. The two canister halves were aligned and held together by guide pins in the flanges. The payload was then weighted and prepared for evacuation in the vacuum chamber.

5.1.3 STRAIGHT FOLD METHOD

The rotating fold method of packing the sphere was used to make use of the space at the sides of the canister. It was believed that this would reduce the stack height of the sphere. However, changes in the sphere inflation system required the sphere to be straight folded. A packing test with sphere 11 using straight folds demonstrated that there was sufficient room in the canister and that packing was easier to perform.

After a test payload had been subjected to a simulated launch vibration and acceleration environment the sphere was found to have shifted and one end of the sphere had become displaced. This difficulty was corrected by installing bolsters in the canister. The bolsters (Figures 5-4 and 5-5) were designed to provide lateral restraint of the sphere, adequate strength to withstand qualification testing, and to remain with the canister halves upon separation. The resulting contoured canister further simplified the packing operation and prevented the sphere from shifting.

The preparations for canister packing required the pleat folds to be repositioned and held in place by vinyl covered tie boards (Figure 5-6). In addition, these boards were designed to protect the CIS bags during the packing sequence and to minimize buildup of residual air inside the sphere. The boards were placed over the pleated stack between air evacuation holes which served to index the lengths of the accordian folds. The sphere was evacuated in a vinyl sleeve under a vacuum of 10 inches of mercury for a minimum of 4 hours prior to packing. By means of a canvas drag cloth under the sleeved unit and attached to a windup on an inclined ramp at the end of the table, the sphere was advanced over the positioned bottom canister half for packing. The accordian folds (Figure 5-7) were made parallel to the canister bolsters, with the tie boards being removed only after the fold into the canister had been made. This method prevented the possibility of bending the controlled inflation bags. The transmitter switches were armed as the center accordian folds were made. Radio receivers and a Sun Gun (Figure 5-8) were used for final circuit check and also to ensure that the switches were closed when armed. The battery packs were installed in the transmitters after the circuit check. Packing was then continued.

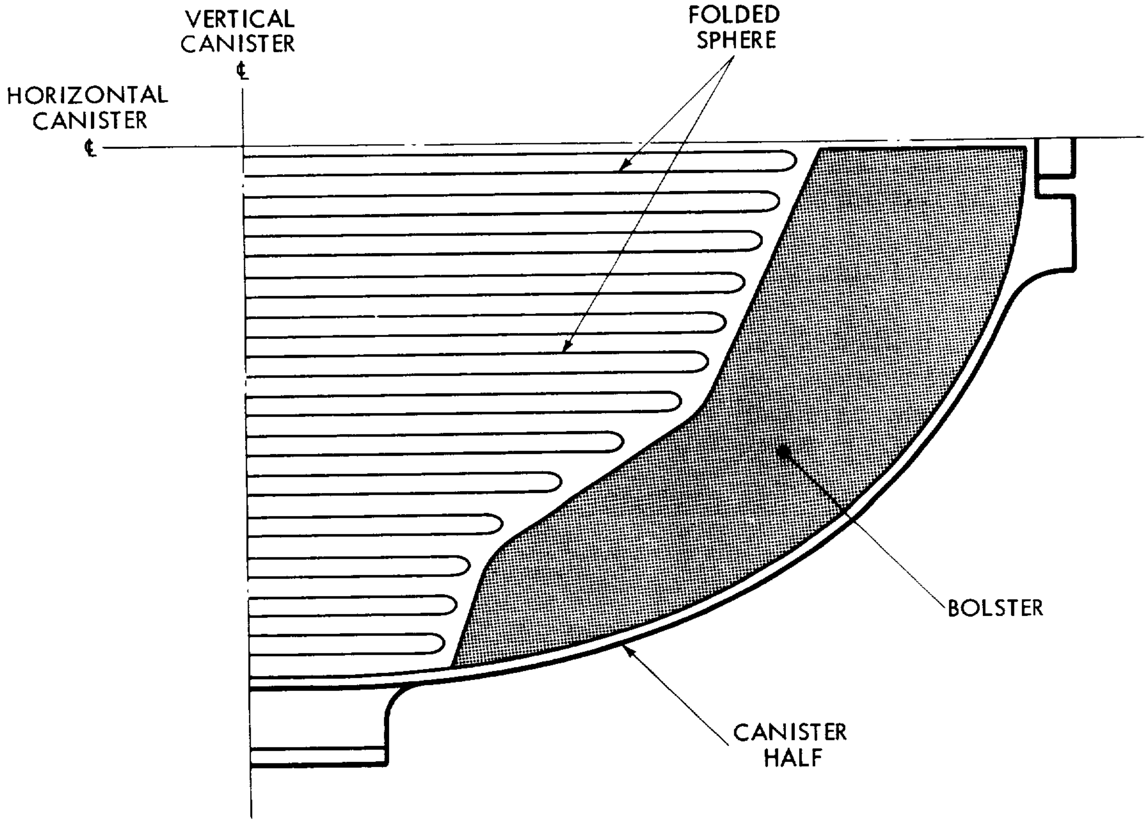


Figure 5-4. Bolster Cross Section

The second half of the sphere was straight accordian folded onto the packed first half keeping the pyramid shape of the stack symmetrical (Figure 5-9). A plastic canister half was then placed over the top of the pyramid stack, and the antenna pull tabs were removed. At this point a heavy vinyl bag previously placed beneath the lower canister half was extended to cover the top half and sealed for application of vacuum. The canister halves were drawn together by intermittently running the portable vacuum pump, and then were held together under vacuum while being transported to the evacuation chamber area.

The two smoke shields (3 mil clear Mylar, 8 inch by 72 inch) were inserted around the parting line of the canister as the plastic top was removed and replaced with the magnesium top (Figure 5-10). The canister halves were aligned, the clearance between the sphere and canister seal area was checked, and the lifting-guide pins were installed. The payload weight was determined before the unit was placed in the evacuation chamber (Figure 5-11).

The orbital backup sphere 17 was packed into canister 8 on December 31, 1963, and the orbital sphere 18 was packed into canister 9 on January 10, 1964, using the straight-fold method.

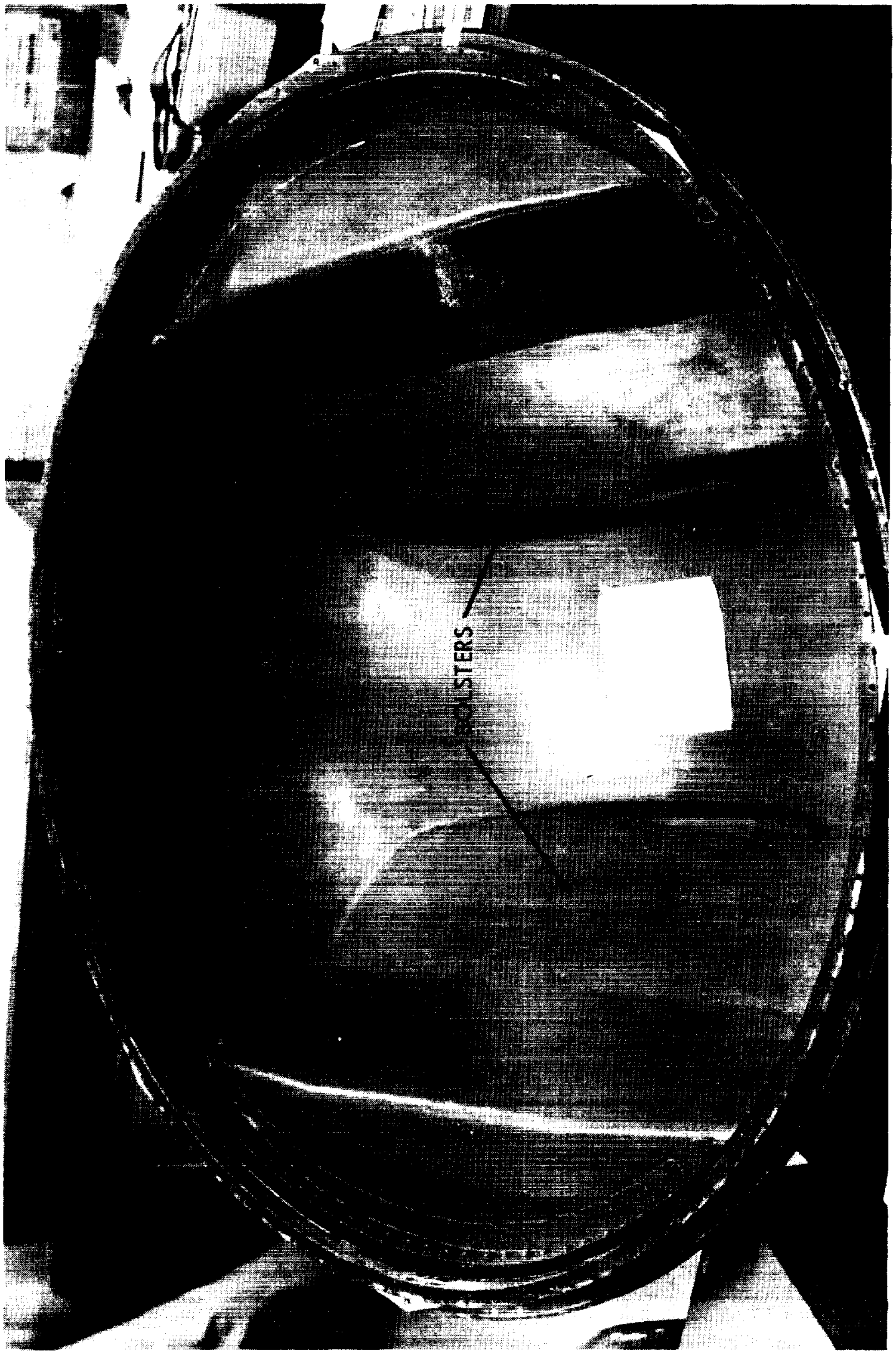


Figure 5-5. Canister Interior Showing Bolsters

Figure 5-6. Sphere Packing Showing Vinyl Covered Tie Boards for CIS

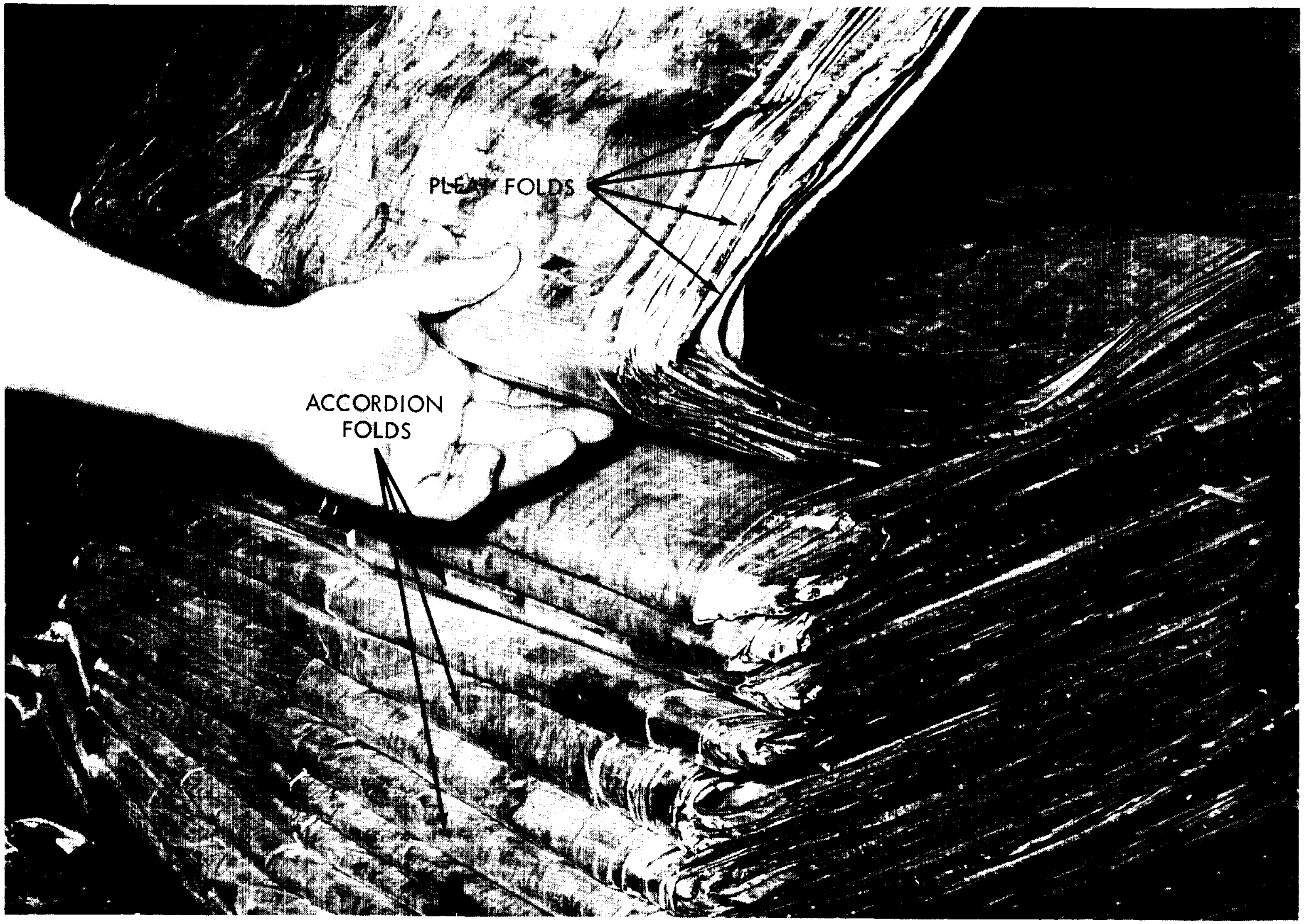


Figure 5-7. Closeup of Sphere Folds, Pleat and Accordion

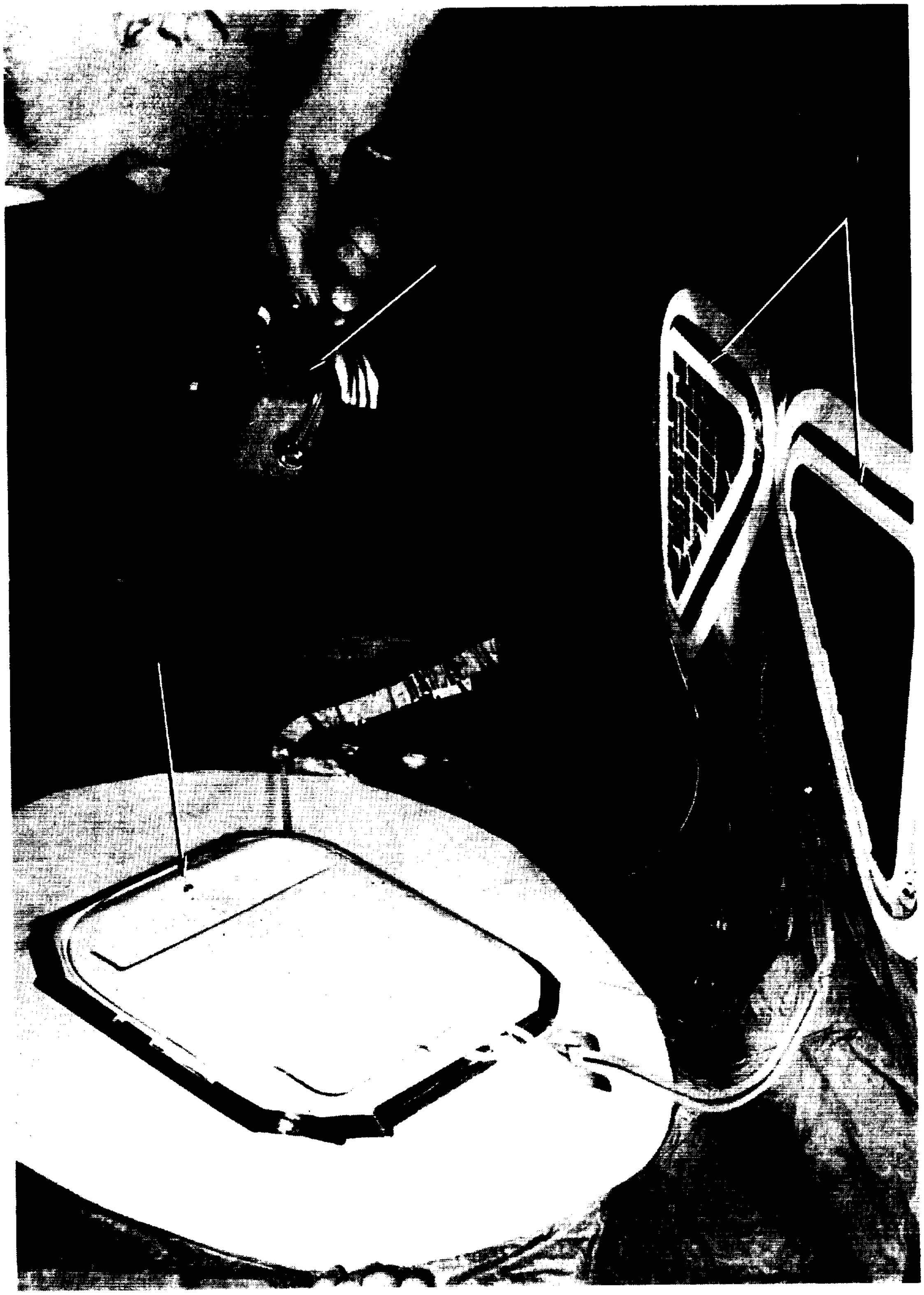


Figure 5-8. Checking the Beacon System

Figure 5-9. Straight Folded Sphere

Figure 5-10. Canister Closing Preparations

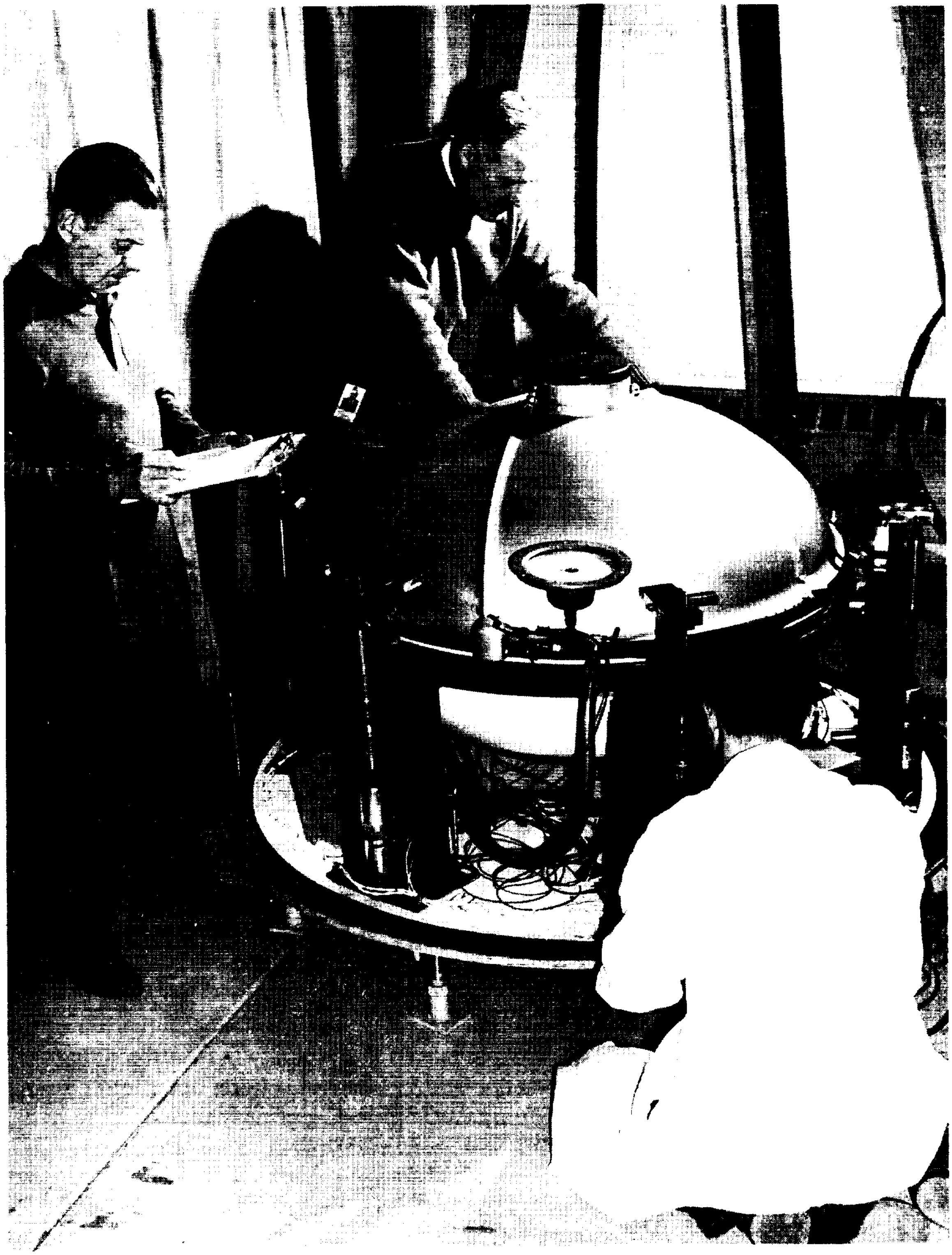


Figure 5-11. Canister with Sphere Prepared for Evacuation

5.2 EVACUATION PROCEDURE

Evacuation of the packed sphere and canister was required to remove residual air and water vapor entrapped in the folds of the sphere. An appreciable amount of residual air or water vapor in the sphere would cause too rapid a deployment and/or over-pressurization resulting in possible rupture of the sphere. The residual air pressure remaining in the canister after evacuation was kept just above the vapor pressure of the inflation compound to preclude premature sublimation.

Equipment for the evacuation operation consisted of a cylindrical steel tank approximately 60 inches in diameter and 60 inches overall height. Evacuation was accomplished with a Kenney K-46 vacuum pump having a capacity of 46 cubic feet per minute. The tank was fitted with a canister support ring, closing ring, closing arms, and six remotely controlled impact wrenches for closing the canister. Pressure and temperature gauges monitored environment conditions in the canister and the vacuum chamber.

The closing mechanism was adjusted manually so that there was an opening of 1/16 inch between the sealing O ring on the top canister half and the mating flange on the bottom canister half. Pumping was controlled so that a pressure drop of not more than 5 mm Hg per minute was maintained until the vacuum tank pressure had been reduced from one atmosphere to the pressure at which continued evacuation was to occur. In the early phases of the program a pressure of 3 mm Hg was maintained for 10 hours. Later, the pressure was lowered to 200 microns for the acetamide system and 950 microns for the pyrazole system and the duration was increased to 24 hours and 48 hours respectively. Following the pumping cycle, the pumps were stopped allowing the sphere and canister to "soak" in the vacuum for 12 hours. This permitted determination of the rate of pressure rise in the tank and canister. From this pressure rise was determined whether or not a leak existed in the system and whether or not premature sublimation of the inflatant was occurring. The soak period was followed by a 3-hour mimimum evacuation at the original evacuation pressure. Table 5-1 summarizes the evolution of the evacuation conditions.

At the end of the evacuation sequence, the canister was closed by actuation of the impact wrenches. The wrenches were actuated individually in rotation using short bursts to avoid over-heating and eventual burnout. Upon complete closing of the canister, the vacuum chamber was vented to the atmosphere and the canister sphere assembly was removed, weighed, and prepared for shipment.

Evacuation of orbital backup sphere 17 in canister 8 was completed January 4, 1964, and shipped to the Western Test Range on January 6, 1964. Orbital sphere 18 in canister 9 was evacuated January 13, 1964, and shipped to the Western Test Range on January 14, 1964.

Table 5-1

Evacuation Sequence History

Sphere	Inflatant	Event	Date	Evacuation Phase 1		Soak Period (hours)	Evacuation Phase 2	
				Pressure (mm Hg)	Duration (hours)		Pressure (mm Hg)	Duration (hours)
3	Acetamide powder	Tank test 1	8-31-61	3	10	10	None	
4	Acetamide powder	Tank test 2	10-1-61	3	10	10	None	
6	Acetamide powder	AVT 1 prime	1-15-62	3	10	10	None	
5	Acetamide powder	AVT 1 backup	1-15-62	3	10	10	None	
		Tank test 3	4-5-62					
10	Benzoic acid powder	Tank test 4	5-9-62	0.2 ±0.1	24	12	0.2 ±0.1	3 minimum
7	Benzoic acid powder	AVT 2 prime	7-18-62	0.2 ±0.1	24	12	0.2 ±0.1	3 minimum
9	Benzoic acid powder	AVT 2 backup	7-18-62	0.2 ±0.1	24	12	0.2 ±0.1	3 minimum
15	Acetamide CIS	VID test 1	7-25-63	0.2 ±0.1	24	12	0.2 ±0.1	3 minimum
14	Pyrazole CIS	VID test 2	10-31-63	0.2 ±0.1	24	12	0.2 ±0.1	3 minimum
12	Pyrazole CIS	VID test 3	12-19-63	0.2 ±0.1	24	12	0.2 ±0.1	3 minimum
17	Pyrazole CIS	Orbital backup	1-25-64	0.95 ±0.05	48	12	0.95 ±0.05	3 minimum
18	Pyrazole CIS	Orbital prime	1-25-64	0.95 ±0.05	48	12	0.95 ±0.05	3 minimum

SECTION 6

TESTING METHODS

6.1 APPROACH

The methods presented in this section were used to determine the quality of the materials and processes used in manufacturing the inflatable spheres. When it was suspected that the samples did not represent the material being tested or when some question of interpretation of results arose, additional samples were tested.

6.2 SAMPLING

A square yard sample was taken from the beginning and end of every roll laminated. The sample was identified with roll number, sample number and machine direction. A square yard sample was taken from selvage material at one end of each gore. The sample was labeled with gore number, roll number and machine direction. The individual tests were performed on portions of the square yard sample.

Samples were taken from the beginning and end of each seal and identified with seal number, sphere number, and sample number.

6.3 WEIGHT DETERMINATION

This test was designed to control the weight of the final sphere by determining the weight of the laminate material during the various phases of the fabrication. Samples 6 inches square were cut with a sharp razor blade and a metal template so that the edges were parallel and free of scratches, notches, and cracks. The sample was weighed to the nearest 0.001 gram on a Mettler gramatic balance. The weight of the laminate without ink or Alodine coating was maintained at 29.9 - 36.5 grams/square yard. The weight of inked and Alodine coated material was maintained at 31.0 - 37.8 grams per square yard.

6.4 DELAMINATION TESTS

These tests were used to indicate delamination or delamination tendency in laminates and seals used in fabricating the inflatable spheres. Any indication of delamination was cause for rejection.

6.4.1 PRESSURE-SENSITIVE TAPE TEST

This test was used to show whether or not areas of delamination which were indicated by visual examination were in fact defects that would interfere with the use of the material. It applied as a quick reference during processing, but was not sufficiently stringent to detect poor sealing or bonding in cured materials.

A strip of pressure-sensitive tape was applied to the laminate material, pressed down firmly, and rapidly pulled off. Any aluminum separations from the laminate was considered delamination. This test was performed at room temperature. The tape extended to the center of each square yard sample. If delamination was found in tests on rolls of material, tests on samples adjacent to individual gores determined disposition of each individual gore.

6.4.2 FLEXURE AND THERMAL SHOCK TEST (ROTATING MANDREL TEST)

This stringent test was applied to ascertain that rigorous conditions would not cause laminate or seals to delaminate. It was used on materials aged a minimum of 24 hours at room temperature. When used on freshly laminated materials a good result would indicate good material but a poor result would not necessarily indicate poor material owing to curing requirements of the adhesive. The test was applied to samples at the beginning and end of each roll of laminate as it was made. It was also applied to both ends of each gore after thermal balance coatings were applied and to both ends of each seal and all samples of tape. One inch by eight inch specimens were placed on a flexure tension jig which caused the material to be flexed 180 degrees around a 1/8-inch diameter rod while being held under tension. The specimen was alternately submerged in a bath of liquid nitrogen (-195°C) and boiling water (100°C) and flexed five times in each for a minimum of 10 complete cycles (100 flexures for each specimen).

6.5 STRENGTH TESTS

These tests were performed to ensure that (1) yield strength levels were sufficiently low to permit rigidizing of the sphere by yielding with internal pressure; (2) ultimate strength levels were sufficiently high to provide a safety factor for containing the internal pressure; and (3) creep resistance was high enough so that seals would not part when exposed to sustained loads at 110°C.

6.5.1 TENSILE TESTS

One inch wide by 8-inch long samples were cut on a precision 1-inch cutter. The samples were representative of the material and were not selected from only good areas of material. The stress strain curve was established for each sample using an Instron tensile machine. These tests were conducted at room temperature with initial jaw separation of 5 inches, crosshead speed of 2.0 inches per minute, and chart speed of 10 inches per minute. For the laminate material, three tests were performed in the machine direction and three in the transverse direction for each sample. The acceptable range of the yield strength was 1.3 - 4.3 lb per inch in the machine direction and 0.9 - 3.8 lb per inch in the transverse direction. The minimum permissible ultimate strength required was 8.4 lb per inch. For the seals, one test was performed perpendicular to the seal for each sample. The minimum acceptable yield strength for the seals was 2.8 lb per inch and the minimum acceptable ultimate strength was 8.4 lb per inch.

Early in the program all tests on laminate material was carried out at extremely slow elongation speeds of 0.02 inch per minute for 5 inch samples. Under these test conditions the yield strength approximated those at higher speeds but the ultimate strength was about 9 pounds per inch and a minimum of 7.5 pounds per inch was assigned for acceptance. In later testing, the rate of strain was increased to 0.2 inch per minute to reduce the testing time from about 1 hour per sample to 5 minutes or less. The rate of strain was increased to 2.0 inch per minute, however, throughout the major portion of the program.

6.5.2 CREEP TESTS

This test was intended to check the adhesive bond of each seal made on all spheres. Two samples, one from each seam end, representative of each seam in the sphere was tested. The sample size was one inch by eight inches. The sample was exposed to a temperature of 110° ±5°C for a period of 24 hours under a constant load of 4 lb per inch. No bond creep was to be present at the end of the test. However, an increase in butt joint separation of 1/16 inch maximum was acceptable. If creepage was indicated the test sample and sphere seal were to be fully evaluated.

6.5.3 DIAPHRAGM BURST TEST

This test was used to check the strength of the material in a bi-axially stressed condition. Four samples 12 inches square were made from the selvage material of each gore and tested in a 10-inch diameter diaphragm tester. Pressure was applied to the test specimen until the specimen ruptured. The pressure at which each specimen ruptured was recorded. The test was performed at room temperature. A minimum average burst pressure of 150 millibars for the four samples was required for acceptance of that particular gore.

6.6 SHRINKAGE TEST

This test was used to determine the residual shrinkage of the gore material following the heat treatment process. Five machine-direction samples were cut 1 inch wide by 14 inches long across the width of each gore sample. Scribe lines 10 inches apart were made across the samples. The samples were restrained with a 200 gram load and the distance between scribe marks measured to the nearest 0.001 inch. The samples, unrestrained, were then subjected to 113 ±3°C for two 3-day periods at atmospheric pressure. Measurement of the samples was made after each exposure, after which the percent shrinkage was calculated.

6.7 THERMAL CONTROL COATING WEIGHT TESTS

6.7.1 ALODINE COATING WEIGHT

This test was used to determine the Alodine coating weight on the exterior and interior surfaces of the sphere skin. The Alodine coating weight directly affects the absorptivity and emissivity of the skin as well as the final weight of the sphere.

Samples were taken during the coating process between each gore at a predetermined point on the web. Three measurements of the top or outside sphere coating weight were made on each sample using the "weight loss after stripping" method. One measurement of the bottom or inside the sphere coating weight employing the same method was made. The measurements were recorded and used in controlling the process for the following gore. The requirements for the Alodine coating were 184 ±3 milligrams/ft^2 for the outside and 150 ±50 milligrams/ft^2 for the inside.

6.7.2 INK COATING WEIGHT

This test was used to determine the ink coating weight on the interior surface of the sphere skin. The ink coating, in addition to the Alodine coating, controls the sphere temperature and affects the total weight of the sphere. Samples 1 ft by 1 ft were taken from the web but not from the actual gore area. The samples were weighed to the nearest 0.01 gram. The ink coating was removed by immersing the samples in a solution of ammonia and distilled water, after which the samples were reweighed to the nearest 0.01 gram. Coating requirements for inking were 0.142 - 0.160 grams/ft^2.

6.8 ABSORPTIVITY AND EMISSIVITY TESTS

The absorptivity of the exterior surface and the emissivity of the exterior and interior surfaces were determined for samples from each gore after Alodine coating and ink coating. A Perkins-Elmer model 13-U spectrophotometer with a hohlraum (heated oven) attachment measured the normal emittance properties. This optical method of measurement is relatively fast and allows handling of large quantities of samples. For calculations involving a spherical shaped satellite, however, the hemispherical emittance rather than the normal emittance is used. A conversion factor was obtained by measuring a few previously measured samples for thermal emittance using a lengthy thermal method which results in a hemispherical emittance value directly. The ratio between the values obtained by both methods is 1.12. So ϵ hemispherical = 1.12 ϵ normal. The average hemispherical emittance value for the satellite was 0.185.

A number of samples were measured for solar absorptance using a Beckman DK-2 spectral reflectometer. The average hemispherical absorptance value for the satellite was 0.261. Since the absorptance is a function of angle of incidence it was necessary to determine an effective value for the hemispherical surface exposed to the sun. This value was obtained by rotating several samples through angles from 0 to 90 degrees and measuring the resulting variation of absorptance with angle of incidence. The effective absorptance value was found to be 0.324. The resulting α/ϵ ratio for the satellite was 1.75.

Other tests were conducted on skin samples to determine if there would be any change in α/ϵ ratio due to long-term exposure to solar radiation and vacuum. The samples were placed in a vacuum of 10^{-5} millimeters of mercury and exposed to a light intensity equivalent to 10 suns for a period of 200 hours. The first α/ϵ measurement was made after approximately 1 hour of exposure. Several more measurements were made after additional exposure and compared with the first measurement. The results indicated no apparent change in α/ϵ ratio with exposure to 200 actual hours of vacuum and 2000 equivalent hours of solar radiation.

REFERENCES

1. Schaefer, R. A., and S. J. Stenlund: Design Manufacture and Test of ECHO A-12 Spheres. Final Report on Contract NAS 1-1138. G. T. Schjeldahl Co., March 1964

2. Miller, V., and P. Kitch: Improved GT-15 Material. Phase Report No. 1 on Contract NAS 5-3243. G. T. Schjeldahl Co., March 31, 1964

3. Stenlund, S. J.: Sealing Improvements Study. Phase Report No. 2 on Contract NAS 5-3243. G. T. Schjeldahl Co., March 3, 1964

4. Stenlund, S. J.: Pleating and Folding Improvements. Phase Report No. 3 on Contract NAS 5-3243. G. T. Schjeldahl Co., February 25, 1964

5. Stenlund, S. J.: Instrumentation Gore Improvement, Phase Report No. 4 on Contract NAS 5-3243. G. T. Schjeldahl Co., February 14, 1964

6. Stenlund, S. J.: Fabrication Improvements, Phase Report No. 5 on Contract NAS 5-3243. G. T. Schjeldahl Co., February 18, 1964

7. Schaefer, R. A.: Fabrication of Three ECHO A-12 Type Spheres. Final Report on Contract NAS5-3522, G. T. Schjeldahl Co., March 1964

8. Staugaitis, C. L. and Kobren, L.: Mechanical and Physical Properties of the ECHO II Metal-Polymer Laminate. NASA TN D-3409, August 1966

9. Staugaitis, Charles L., and Kobren, Lawrence: Strain Measurements Conducted on a Full Scale ECHO II Passive Communications Satellite Balloon. NASA TN D-3126, March 1966

10. Cleereman, K. I., H. J. Karam, and J. L. Williams: Polystyrene Monofilaments Bristles. Modern Plastics. 30, No. 9, p. 119, 1953

11. Wirth, R. J.: Thermal Control of ECHO II Satellite. Informal Report, May 1964

12. Patent No. 3,276,726. Inflation System for Balloon Type Satellites. Inventors: John M. Thole, Wallace S. Kreisman, and Robert M. Chapman. Issue Date: October 4, 1966

13. Development of a Controlled Inflation System and Beacon Buffer System for the ECHO A-12 Passive Communication Satellite. Technical Report prepared under Contract NAS5-1888. GCA Viron Div., April 1964

14. Hall, J.: ECHO Gore Drop Tests in the GSFC Dynamic Test Chamber, March 18-22, 1963. GSFC T&E Memorandum Report No. 631-127. April 15, 1963

15. Hall, J.: ECHO Gore Drop Tests in the GSFC Dynamic Test Chamber, April 8-12, 1963. GSFC T&E Memorandum Report No. 631-135. May 3, 1963

16. Monthly Status Report for January 1964 for Project ECHO A-12. Prepared under Contract NAS1-1231. Grumman Aircraft Engineering Corp., February 1964

APPENDIX A
ECHO II SPHERE HISTORY

Sphere	Test or Event	Date	Canister	Design or Process Change (Apply to all Subsequent Units)	Remarks
1	Packing test	4/20/61	1		Subliming material simulated with corn starch
2	SIT - Weeksville, N. C.	5/15/61	-	Ultrasonic jumper strip added	
3	Tank test 1 - LRC	8/31/61	2	Acetamide inflatant and red dye added; alum. alloy changed 1145 to 1080	
4	Tank test 2 - LRC	10/1/61	4		
5	AVT 1 - Standby ETR Tank test 3 - LRC	1/15/62 4/5/62	7 5	Alodine coating added; acetamide changed to reagent grade	Repaired and repacked 3/15/62 for tank test
6	AVT 1 - Prime ETR	1/15/62	6	Alodine top weight specified	
7	AVT 2 - Prime ETR	7/18/62	7	Alodine bottom weight specified Benzoic acid inflatant India ink spray coated Reinforced instrumentation gores	
8	Evacuation sequence test	12/21-29/63	4 bottom plastic top		Fabricated into display model for N. Y. World's Fair 1964-1965 and GSFC
9	AVT 2 - Standby AMR SIT - Lakehurst, N. J.	7/18/62 1/19/63	-		
10	Tank test 4 - LRC	5/9/62	3		No jumper strip

Sphere	Test or Event	Date	Canister	Design or Process Change (Apply to all Subsequent Units)	Remarks
11	SIT - Lakehurst, N. J.	1/13/63	-		Thermal coating tolerance waived No inking Premature rupture at 6200 psi due to material defect
12	Spacecraft launch environment test		5	India ink roll coated Controlled inflation system adopted	
	VID 3 - GSFC	12/19/63	5	Bolsters added to canister	
13	SIT - Lakehurst, N. J.	7/10/63	-		Ruptured at 11,200 psi in duct attachment area
14	Spacecraft launch environment test	10/23-28/63	4		
	VID test 2 - GSFC	10/31/63	4		
15	Spacecraft launch environment test Qualification level	5/3-14/63	5		No bolsters in canister; sphere shifted
	Spacecraft launch environment test Flight levels	5/18-24/63	1A		Sphere repacked in new canister with bolsters
	VID test 1 - GSFC	7/25/63	1A		
16	SIT - Lakehurst, N. J.	12/18/63	-		Thermal coating tolerance waived No ink required Ruptured at 22,900 psi
17	Orbital - Standby WTR	1/25/64	8	Pyrazole inflatant	Sphere unpacked and inspected for storage effects, structural, continuity Made into display model
18	Orbital - Prime WTR	1/25/64	9		

APPENDIX B
ECHO II CHRONOLOGY OF EVENTS

Event	Date	Sphere	Canister	Inflatant	Remarks
Packing test GTS	4/20/61	1		Subliming material simulated with corn starch	
SIT - Weeksville, N. C.	5/15-19/61	2			
Spacecraft launch environment test Qual. levels GAEC/TRW	8/7-18/61	3	2	Acetamide powder	
Tank test 1 - LRC	8/31/61	3	2	Acetamide powder	
Tank test 2 - LRC	10/1/61	4	4	Acetamide powder	
AVT 1 - AMR	1/15/62	6	6	Acetamide powder	Sphere 5 in Canister 7 Backup
Tank test 3 - LRC	4/5/62	5	5	Acetamide powder	
Tank test 4 - LRC	5/9/62	10	3	Benzoic acid powder	
AVT 2 - AMR	7/18/62	7	7	Benzoic acid powder	Sphere 9 in Canister__ Backup
Packing test with CIS	4/18/63	11		CIS simulated with masonite boards	Provided folds for SIT test
Spacecraft launch environment test Qual. levels GAEC	5/3-14/63	15	5	CIS-Acetamide	Sphere shifted in canister
Spacecraft launch environment test Flight levels GAEC	6/18-24/63	15 repacked	1A	CIS - Acetamide	Canister modified with Bolsters
SIT - Lakehurst, N. J.	6/13/63	11			Ruptured at 6,200 psi material defect
SIT - Lakehurst, N. J.	6/19/63	9			Ruptured at 4,200 psi
100% area inspection of spheres 8,12,13 for material defect	6/21-23/63	8,12,13			
SIT - Lakehurst, N. J.	8/10/63	13			Ruptured at 11,200 psi

Event	Date	Sphere	Canister	Inflatant	Remarks
VID - GSFC	7/25/63	15	1A	CIS - Acetamide	
Spacecraft launch environment test Flight levels GAEC	10/23-28/63	14	4	CIS - Pyrazole	
VID - GSFC	10/31/63	14	4	CIS - Pyrazole	
VID - GSFC	12/19/63	12	5	CIS - Pyrazole	
SIT - Lakehurst, N. J.	12/18/63	16			Ruptured at 22,900 psi
Evacuation sequence test	12/21-29/63	8	4 bottom plastic top		
Orbital launch - WTR	1/25/64	18	9	CIS - Pyrazole	Sphere 17 in Canister 8 backup
Inspection of backup sphere for storage effects	4/20-24/64	17	8	CIS - Pyrazole	

APPENDIX C

SPECIFICATION
FOR
FABRICATION AND PACKAGING OF 135-FOOT DIAMETER ECHO A-12 INFLATABLE SPHERES

AUGUST 12, 1963

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

August 12, 1963

SPECIFICATION
FOR
FABRICATION AND PACKAGING OF 135-FOOT DIAMETER ECHO A-12 INFLATABLE SPHERES

1. General Description

This specification is to cover the construction and packaging of a rigidized passive spherical satellite 135 feet in diameter. The basic laminate from which this satellite shall be fabricated is to be a 3-ply laminate consisting of 0.18 mil thick aluminum alloy foil bonded on each side of 0.35 mil thick Mylar* film. The total thickness of this 3-ply laminate shall be approximately 0.71 mil. The four instrumentation gores, that is the gores on which the beacons and solar modules are to be mounted, shall be made from a 4-ply laminate. This 4-ply laminate shall consist of the 3-ply basic laminate with an additional 0.5 mil thick Mylar film on the inner surface of the gore. The approximate total thickness of these instrumentation gores shall be 1.21 mil. The sphere shall be composed of 106 gores, 48 inches wide which terminate at a polar cap. The edges of each gore shall butt with the adjoining gore and the seam shall be made of a strip of laminate material which is used as a splice plate and sealed to each gore. The construction of the polar cap as well as the method of attachment of the polar cap, shall be by the same process stated above.

2. Scope of the Specification

This specification covers the materials and services required for this operation as well as the testing program that is required to verify the integrity of the inflatable sphere, materials, and methods used in its production.

It includes tests made at manufacturer's plant, the NASA's Goddard Space Flight Center and other facilities as required.

This specification shall cover raw material, lamination, coating, gore preparation, sealing, folding, installation of end caps, jumper strip, instrumentation, controlled inflation system, red fluorescent dye, air orifices, and sphere packing and evacuation.

*Trade Name E. I. duPont deNemours and Co., Inc.

3. Materials

3.1.1 Basic Laminate Material—The basic laminate material shall consist of 0.18 mil aluminum foil bonded to both sides of 0.35 mil Mylar* plastic film. Adhesive bonds shall be provided to insure that delamination will not occur, and the laminate shall have a minimum strength of 5.25 lb/in. To insure that the preceding value is maintained, testing shall be performed at 8.4 lb/in. minimum.

3.1.1.1 Aluminum Foil—The aluminum foil shall be 0.18 ±10% mil thick and composed of alloy 1080 (99.9 minimum % al).

3.1.1.2 Mylar*—The Mylar film shall be 0.35 mil thick (±10%) du Pont Type C with a minimum tensile strength of 17,000 psi in both longitudinal and transverse directions. The film shall have minimum elongation of 70% and shall be free of holes and scratches. Percent shrinkage shall be determined for each roll of Mylar film prior to lamination.

3.1.1.3 Adhesive—The adhesive used shall be G T. 301** applied to give a coating thickness of about 0.01 mil.

3.1.1.4 Lamination Process—The lamination shall be carried out to provide material to conform to Table 1 below:

Table 1

	Method	No. Samples & Location	Allowable Limits
Weight/Ft^2	11.1.1	2 - Start and End	3.32-4.05 grms/ft^2
Delamination	11.2.1	As need to suspect areas	None
	11.2.2	6-Start & End Across Web	None
Yield Strength	11.3.1	3-Transverse Direction (left edge, center, right edge)	0.9 - 3.8 #/in
	11.3.1	3-Longitudinal Direction (left edge, center, right edge)	1.3 - 4.3 #/in
Ultimate Strength	11.3.1	Same as yield strength	8.4 lbs/in Min
Stressed Areas	Visual	-	6" max 3 places max per gore
Fold and Wrinkles	Visual	-	None sealed with Mylar
Shrinkage at 110° C			

*Trade Name duPont
**GTS Co. Proprietary Item

3.1.2 Reinforced Laminate Material—Certain areas of the sphere structure which will be subjected to high stress conditions are the pole cap areas and the gores to which beacons and other instrumentation devices are attached. These materials shall therefore contain additional Mylar to insure high strength.

3.1.2.1 Pole Cap Material (GT-16)—The material to be used for the pole cap area shall be made of laminate similar to the basic laminate material (3.1.1) but made from 0.18 mil aluminum foil on both sides of 1 mil Mylar.

3.1.2.2 Instrument Gore Material (GT-91)—Instrument gore material shall be made by laminating alodine coated GT 15 (3.1.1 and 3.1.3.1) to a layer of 0.5 mil Mylar.

3.1.3 Thermal Control Coatings—It will be necessary to apply coatings on the laminate to accomplish thermal control of the satellite. The satellite will require on its inner surface a uniform coating of high emissivity to minimize temperature variation over the satellite. On its exterior surface it will require a low absorptivity emissivity ratio to attain the desired temperature level.

3.1.3.1 Alodine Coating Material—The material used to provide an inorganic thermal control coating will be a solution mixture of Alodine* 401 and Alodine* 45.

3.1.3.2 Ink Coating—The ink coating to be used shall be Higgins #44 Waterproof India Ink or equivalent.

3.1.3.3 Alodine Process—The alodine coating shall be applied in a continuous roll to roll process operated to give a coating weight to 184 ± 3 mg/ft^2 on the exterior surface and 150 ± 50 mg/ft^2 on the interior surface. The concentration of the materials in the coating bath shall be maintained at steady state levels by continuous withdrawal and replenishment.

In this process gore selection marks shall be put on the material so that test sample can be removed at both ends of each gore.

*Trade Name Amchem Inc.

3.1.3.4 Ink Coating Process—The india ink shall be applied to the interior surface of the balloon skin by a continuous roll coating process to give an even coating corresponding to 15-20 lbs total weight added to the finished 135 ft diameter sphere. The emissivity of the inked surface shall be 0.8 ±0.1. Individual voids in the coating shall not exceed the area of a circle 0.75 inches in diameter. The coating shall be firmly adherent and exhibit minimum tendency to flake.

4. Fabrication

Fabrication processes shall be carried out to insure as accurate a spherical shape as possible for most efficient reflection of electromagnetic radiation. In addition, seal areas are to provide electrical continuity and sufficient structural integrity to withstand an internal pressure corresponding to a load of 5.25 lb/in. To insure that the preceding is maintained testing shall be performed at 8.4 lb/in minimum. The seals shall show no bond creep; however, an increase in butt joint separation of less than 1/16" per 24 hours when supporting 4 lbs/in at 110° C is acceptable.

4.1 Gore Cutting—The gores are to be cut to the dimensions and tolerances shown in Table 2.

4.1.1 Gore Locations—All gores are to be of basic laminate material except 53, 54 and 1 and 106 which are to be reinforced instrument gore material.

4.2 Seam Construction

4.2.1 Seal Tape Material—The seal shall be cut in the longitudinal direction from alodine coated basic laminate material. The seal tape shall be coated with 0.5 ±0.2 mil of G.T.301 adhesive. The width of the tape shall be one (1) inch. The tape will bond the gores together in a butt type joint and will be on the outside of the laminate gore material. There shall be a minimum of 3/8 inch of tape in contact with each gore at any point along the butt joint of the seam length. Overlap and gap shall not exceed 0.2 inch overlap or 0.04 inch gap between gores at the butt joint.

4.2.2 Application of Seal Tape—The seal tape shall be applied to the gore material in a manner that will produce the highest quality seal possible with an absolute minimum of handling of the Echo A-12 laminate material.

Table 2

Gore Dimensions

Distance From Gore Center			One Half Width Inches
Ft.	Inches	Tol.	
0	0	±0.040	24.006
2	4.260	±0.040	23.991
4	8.532	±0.040	23.947
7	0.804	±0.040	23.874
9	5.076	±0.040	23.772
11	9.336	±0.040	23.641
14	1.608	±0.040	23.481
16	5.880	±0.040	23.292
18	10.224	±0.040	23.076
21	2.496	±0.040	22.831
23	6.684	±0.040	22.558
25	11.040	±0.040	22.257
28	3.300	±0.040	21.930
30	7.572	±0.040	21.576
32	11.844	±0.040	21.196
35	4.116	±0.040	20.789
37	8.376	±0.040	20.358
40	0.648	±0.040	19.901
42	4.920	±0.040	19.421
44	9.192	±0.040	18.916
47	1.452	±0.040	18.389
49	5.724	±0.040	17.839
51	9.996	±0.040	17.268
54	2.340	±0.040	16.676
56	6.612	±0.040	16.063
58	10.800	±0.040	15.430
61	3.156	±0.040	14.779
63	7.416	±0.040	14.110
65	11.688	±0.040	13.423
68	3.960	±0.040	12.721
70	8.232	±0.040	12.003
73	0.492	±0.040	11.270
75	4.764	±0.040	10.523
77	9.036	±0.040	9.764
80	1.308	±0.040	8.992
82	5.568	±0.040	8.210
84	9.840	±0.040	7.418

Table 2 (Continued)

Gore Dimensions

Distance From Gore Center			One Half Width Inches
Ft.	Inches	Tol.	
87	2.112	±0.040	6.617
89	6.456	±0.040	5.807
91	10.728	±0.040	4.991
94	2.916	±0.040	4.168
96	7.272	±0.040	3.340
98	11.532	±0.040	2.509
101	3.804	±0.040	1.674
103	8.076	±0.040	.837
106	0.348	±0.040	0

The sealer shall be capable of producing gas tight and wrinkle free seals with strength equal to 100% of parent material in the length required. There shall be no folds or pleats placed in the gore as a result of the sealing operation. The last seal shall be made after the installation of the controlled inflation system and shall be of equivalent quality to that of the other seals.

4.2.3 Seal Properties—The seals in the balloon shall be free of wrinkles. Samples from both ends of each seam and test seals of each roll of tape shall meet the specifications in Table 3.

Table 3

	Acceptable Range	Method
Gap	.04" Max.	Visual
Overlap	.02" Max.	Visual
Creep 110°	1/16 in Max.	11.3.2
Ultimate Strength	8.4 lb/in Min.	11.3.1
Delamination	None	11.2.2
Puckering	None	Visual
Mis-Match of Alignment Marks	±1/8 inch at stations O, 44N, 44S ±1/4 at all other stations	Visual

4.3 Air Orifices—The sphere shall have air orifices to permit the entrapped residual air to be evacuated from the inside of the inflatable sphere prior to closing the canister. Each air orifice shall be 1/16 inch in diameter, and shall be reinforced with a circular patch. The circular reinforcement patch shall be about one (1) inch in diameter and it shall be made from the same type of material as the gores and splice plate. The reinforcement patches shall be located on the outside surface of the 135-foot diameter inflatable sphere. The air orifice holes shall be punched through the reinforcement patch and the gore material after the reinforcement patch has been sealed on the surface of the inflatable sphere.

4.3.1 Location of Air Orifices—The air orifices and reinforcement patches shall be located along the meridian lines of the sphere that coincides with the center line of the stack formed by pleat folding the sphere. However, the air orifices and reinforcement patches shall be omitted in the general area of the instrumentation on the inflatable sphere.

The first four (4) accordian folds on either side of the equator will not have orifice holes. All other accordian folds shall have at least one (1) air orifice hole located on the outside of the fold. The total number of air orifice holes shall be about 225 and the total hole area shall equal about 3/4 of 1 square inch in the hole area.

4.4 Electrical Continuity & Jumper Strip—A jumper strip of non-alodine coated GT-15 material, one half inch wide shall be ultrasonically welded to the sphere, between the seals on each gore. One jumper strip shall be installed on each end of the sphere around a circumference approximately two inches from the pole cap. The purpose of the strip is to insure D. C. continuity on the surface of the sphere. This is done in addition to continuity provided by intimate contact of gores through the butt joint when sealed. Therefore it is required that the alodine coating be removed on an area of approximately one-fourth inch square on each gore where the ultrasonic weld is to be made. After the ultrasonic welding has been completed, the jumper strip and adjacent gore shall be vented near the weld to preclude the possibility of entrapping. The continuity jumper strip shall then be sealed over with 1 inch wide sealing tape to prevent gas leakage.

4.5 End Caps—End caps shall be fabricated from GT-16 reinforced laminate material (3.1.2.1) and shall be 52 inches in diameter. The end caps shall be attached to the gore material with GT-301 heat sealable adhesive.

5. Defect Repair

5.1 Repairable Defects—Certain defects or damaged areas may be reinforced by patching with seal tape. Repairable defect shall include:

Holes one inch diameter or less
Tears six inch long or less
Stretch marks not exceeding 6 inches long, providing they extend from the edge of the tailored (cut) gore.
Delamination less than 1/2 inch wide and 12 inches long.

A defect that shall not require repair is a break in the foil not exceeding 2 inches in length that occurred before lamination. This defect can be differentiated from a stretch mark, as only one layer of foil will be broken while the foil on opposite side of the Mylar will be intact.

5.2 Repair requirements—All repairs shall be made according to acceptable standards and shall meet the following basic requirements:

a. The width of patching tape shall be 1 inch minimum and 3 inches maximum.

b. The minimum width of bond area around any reinforcement patch shall be 1/2 inch.

c. All patched defects must be vented to the inside of the sphere.

d. Voids, air bubbles, creases and wrinkles shall not exist.

e. No stress concentration shall appear when the patched area is drawn taut.

f. The edges of all repair tapes shall be resistant to peeling away from the parent material.

An acceptable gore shall have no more than a total of three repairs. A record of all repairs shall be maintained as to size and location.

6. Instrumentation

Instrumentation and/or simulated instrumentation, instrumentation reinforcement patches, thermal control disks, skuff pads, and pull tabs shall be installed on the reinforced gores 180 degrees apart at the equator. Installation shall be of the highest quality and shall not adversely affect the surface contour of the sphere.

7. Installation of Controlled Inflation System

A controlled Inflation System shall be attached to the inner surface of the sphere. It shall consist of approximately 72 individual bags each containing sublimation material. The bags shall be attached so that no deformation of the surface contour occurs. The attachment shall be made in the sphere at the location shown in Table 4.

Table 4

Place Bags Between Folds	Pleat Pocket Nos.	Bag Size
24-25	55	
25-26	40	
26-27	72	
27-28	23	B
28-29	62	9-1/2" x 25-1/2"
29-30	33	
30-31	85	
31-32	10	
32-33	52	
33-34	43	
34-35	78	
35-36	17	
36-37	67	A
37-38	28	12" x 24"
38-39	57	
39-40	38	
40-41	87	
41-42	8	

8. Installation of Red Fluorescent Dye

Red Fluorescent Dye shall be applied to the inner surface of the sphere to preclude the possibility of blocking due to tack caused by residual traces of adhesive in the seal area. The total dye weight added to the sphere shall be about 8 lbs.

9. Packaging the Inflatable Sphere

The sphere shall be folded and then packaged in an oblate spheroid canister.

9.1 Position of Instruments in Package—The inflatable sphere shall be folded so that the beacon packages will be located within the two center accordian folds. Special care shall be taken in handling to insure against damaging the instruments.

9.2 Pleating Pattern—The sphere shall be pleated from pole to pole except for approximately the last 30 feet at the poles. There shall be approximately 3.4 pleats per gore width except in the last 30 feet at each pole, where the pleats will be dropped as required to maintain a final pleat width equal to the pleat width, at a point 30 feet from the pole.

9.3 Accordian Folds—The sphere shall be zig-zag folded in such a manner that it will fit into the Echo A-12 canister. To fit the contour of the canister, the center folds will be approximately 26 inches long with folds increasing to approximately 35 inches long and then decreasing to a minimum of approximately 18 inches long for the final folds of the pole cap.

10. Evacuation of Inflatable Sphere and Canister

With the sphere contained within the canister and with the use of special clamps and equipment, an opening of 0.1 inch at the joint of the two (2) canister halves shall be maintained during the evacuation procedure so that the residual air in the sphere and canister may be removed. The canister, with packaged sphere, shall be placed in a suitable vacuum chamber (maintaining a vacuum of 0.1 mm Hg) subjected to a specified vacuum for the required length of time, and then closed using a remotely controlled mechanical closing device. After a satisfactory closure, the chamber shall be vented to atmospheric pressure and the payload removed.

10.1 Evacuation and Closing Procedure—A pressure drop not greater than 5 mm Hg/min shall be maintained until the pressure in the chamber has been reduced from one atmosphere to 200 ±100 microns Hg. Pressure at 200 ±100 microns shall be maintained for 24 hours with pumps operating. After 24 hours the pumps shall be shut off and the payload shall soak for 12 hours. After the 12 hour soak period the chamber shall be re-evacuated to 200 ±100 microns which shall be maintained for 3 hours. At the end of the 3 hour hold period the canister shall be closed in 1/16 inch increments by actuating the remotely controlled closing mechanism. The chamber shall then be returned to atmospheric pressure and the canister removed.

10.2 Residual Air in Canister—The amount of residual air in the canister with sphere installed shall be maintained between 1 mm Hg and 3 mm Hg at 25° C.

11. Testing Methods

The methods presented in this section are to be used by the contractor to define the quality of the materials and processes used in the manufacture of the inflatable spheres.

11.1 Weight Per Unit Area—These tests are designed to control the weight of the final sphere.

11.1.1 Square Yard Test—One square yard of material shall be cut at the end of each gore and weighed to the nearest 1/100 gram. This weight shall then be used to calculate the weight per unit area in grams per square foot.

11.1.2 Small Area Tests—Smaller pieces of laminate, film or foil shall be weighed to the nearest 1/100 gram to indicate unit area weights of in process materials.

11.2 Delamination Tests—The tests outlined below are to be used to indicate delamination or delamination tendency in laminates and seals used in fabricating the inflatable spheres.

11.2.1 Scotch Tape Test—This test is to be used to show whether areas of delamination which are indicated by visual examination are defects that may interfere with the use of the material. It applies a quick reference test during processing but is not sufficiently stringent to detect poor sealing or bonding in cured materials.

A strip of pressure sensitive tape (scotch tape) shall be applied to the laminate material, pressed down firmly and rapidly pulled off. Any aluminum separations from the laminate shall be considered delamination. This test shall be performed at room temperature.

11.2.2 Rotating Mandrel Test—This stringent test is to be applied to ascertain that rigorous conditions will not cause laminate or seals to part. It should be used on materials aged a minimum of 24 hours at room temperature. When used on fresh materials a good result will indicate good material but a poor result may not indicate poor material.

11.2.2.1 Sample Selection—The test should be applied to samples at the beginning and end of each roll of laminate as it is made. It is also to be applied to both ends of each gore after thermal balance coatings have been applied. It is also used to test both ends of each seal and all samples of G.T. 301 tape.

11.2.2.2 Test Procedure—Test samples one inch wide, eight inches long shall be placed on an oscillating tension jig which will rotate the sample 180° around an 1/8 inch diameter mandrel. The jig will then be dipped alternately in baths of liquid N_2 (-195° C) and boiling water (100° C) and flexed five times in each bath for at least ten complete cycles (100 flexures) for each specimen.

11.3 Strength Properties—These tests are to be performed to insure that 1) yield strength levels are sufficiently low to permit rigidizing of the sphere by yielding with internal pressure; 2) ultimate strength levels are sufficiently high to provide a safety factor for containment of the internal pressure and 3) creep resistance is high enough so that seals will not part when exposed to sustained loads at 110° C.

11.3.1 Instron Tests—One inch wide by 8" long samples shall be cut on a precision 1" cutter. The samples are to be representative of the material and should not be selected from only good areas of material. The nature of the stress strain curve is to be established for each sample.

11.3.1.1 Standard Instron

Jaw Separation	5 inches
Head Speed	2.0 inches/minute
Chart Speed	10 inches/minute
Temperature	Room temperature

11.3.2 Creep Strength—This test is intended to check the adhesive bond of each seal made on the balloon.

Two samples, one from each seam end, representative of each seam in the balloon shall be tested. The sample size shall be one by eight inches and prepared for creep tests. The sample shall be exposed to a temperature of 110°C ±5°C for a period of 24 hours under a constant load of 4 #/in.

No bond creep shall be present at the end of the test, however, an increase in butt joint separation of 1/16 inch max. is acceptable. If creepage is indicated the test sample and balloon seal shall be fully evaluated.

11.3.3 Bulge Test—This test shall check the strength of the material in a bi-axially stressed condition. Samples shall be tested in a bulge tester approximately 12 inches in diameter. Pressure or vacuum shall be applied to the test specimen at the rate of about 60 mm/min until the specimen ruptures. The pressure at which each specimen ruptures shall be recorded. Test shall be performed at room temperature.

11.4 Coating Weight Tests

11.4.1 Alodine Coating Weight—This test is intended to determine the alodine coating weight on the exterior and interior surfaces of the balloon skin. The alodine coating weight directly affects the absorptivity and emissivity of the skin as well as the final weight of the balloon.

Samples shall be taken during the coating process between each gore at a predetermined point on the web. Three measurements of the top or outside sphere coating weight shall be made on each sample using the "weight loss after stripping" method. One measurement of the bottom or inside the sphere coating weight employing the same method shall be made. The measurements shall be recorded and used in controlling the process for the following gore.

11.4.2 Ink Coating Weight—This test determines the ink coating weight on the interior surface of the balloon skin. The ink coating, in addition to the alodine coating, controls the balloon temperature and affects the total weight of the balloons. Samples 1 ft by 1 ft shall be taken from areas marked as restart at Alodine operation if possible, but not from the actual gore area. The samples shall be weighed to the nearest 1/100th gram. The ink coating shall be removed by immersing the samples in a solution of ammonia and distilled water. After which the samples shall be reweighed to the nearest 1/100th gram.

11.5 Absorptivity and Emissivity Tests—The absorptivity of the exterior surface and the emissivity of the exterior and interior surfaces shall be determined by GSFC for samples from each gore after alodine and ink coating. Instrumentation relative to sample size shall be furnished by GSFC prior to requirement for delivery of samples.

12. Quality Control

Quality Control procedures shall conform to NASA Specification NPC 200-2. Quality Control shall be maintained on the raw material, lamination, coating, gore preparation, sealing, folding, installation of end caps, jumper strip, instrumentation, controlled inflation system, red fluorescent dye, air orifice, packing, and evacuation. Complete written procedures and quality control check lists shall be prepared on each operation. These procedures and check lists shall be supplied with each inflatable sphere.

APPENDIX D

LIST OF G. T. SCHJELDAHL CO. SPECIFICATIONS FOR FABRICATION AND PACKAGING OF THE ECHO II SATELLITE

	GTS Co. Spec.	Date Issued	Revision
Lamination of GT-15-2 material	GTX-15-2	8-25-63	C
Lamination of GT-15-3 material	GTX-15-3	8-26-63	D
Lamination of reinforced gores	X-91	10-5-62	
Alodine coating	P-55	10-16-61	G
Alodine coating	P-66	2-25-62	A
Ink coating	P-226	9-26-63	D
Ink coating	P-246	12-8-63	
Heat treatment	P-227	10-1-63	
Gore cutting	P-228	10-5-63	D
Sealing	P-240	11-6-63	B
Sealing	Q-38	11-8-63	
Testing	Q-17	10-24-62	F
Repair of material	P-11	3-15-62	B
Beacon reinforcement patches	P-243	11-26-63	D
Reinforced gore installation	P-119	12-21-62	E
Air orifice	P-114	5-9-62	B
Ultrasonic jumper strip	P-28	1-8-62	
End caps	P-44	5-8-61	A

	GTS Co. Spec.	Date Issued	Revision
Pleating	P-245	12-5-63	
Beacon installation	P-97	11-25-61	G
Dye installation	X-329	6-10-63	
Controlled inflation system installation	P-201	4-23-63	A
Controlled inflation system installation	Q-39	11-17-63	
Canister packing	P-50	12-21-61	D
Evacuation	P-26	4-25-63	C
Quality control program	Q-18	10-24-62	B

APPENDIX E

CONTRACTORS PARTICIPATING IN THE DEVELOPMENT AND FABRICATION OF THE ECHO II SATELLITE

Contractor	Responsibility	Contract No.
G. T. Schjeldahl Co. Northfield, Minn.	Development, fabrication and packaging of the inflatable sphere	NAS 1-1138 NAS 5-3243 NAS 5-3522
GCA Viron Division Aroka, Minn.	Development and fabrication of the controlled inflation system	NAS 5-1888
Grumman Aircraft Engineering Corp. Bethpage, L. I., New York	Development and fabrication of the canister	NAS 1-1231
Aero Geo Astro Corp. Alexandria, Virginia	Development and fabrication of the beacon telemetry system	NAS 5-3463 NAS 5-2583
Taag Designs, Inc. College Park, Md.	Quality control and reliability assurance	NAS 5-2832
Bower Associates Inc. Minneapolis, Minn.	Evaluation of and reporting on quality control and reliability assurance	NAS 5-3915